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Investigating the relationship between social deprivation and health outcomes in China: using spatial regression analysis approach

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Abstract

Background Although significant progress has been made in the health status of Chinese citizens, disparities are still strikingly evident. This paper reveals the interconnection between social deprivation and the health of the Chinese population using the latest census data, and delves into the impact of social deprivation on health outcomes.

Methods To assess social deprivation, this study selected 14 indicators from six domains: income, employment, education, housing condition, housing area, and demographic structure. The social deprivation value was calculated using entropy method, variation coefficient method, CRITIC method, and principal component analysis method, and its spatial distribution was compared. Meanwhile, the best models are selected from ordinary least squares regression models, spatial lag models and spatial error models to analyze the effect of social deprivation on health outcomes according to the performances of these models.

Results The spatial distribution of social deprivation in China displays notable heterogeneity. The best models indicates that social deprivation is negatively correlated with mortality rate of Class A and B infectious diseases, average life expectancy and proportion of healthy elderly, but positively correlated with incidence rate of Class A and B infectious diseases, maternal mortality rate, and prevalence rate of low-weight children. The part of regression models for analyzing the relationship between social deprivation and metrics like incidence rate of infectious diseases, maternal mortality rate, average life expectancy, and proportion of healthy elderly are in the form of spatial lag. The part of regression models for analyzing the relationship between social deprivation with mortality rate of Class A and B infectious diseases and prevalence rate of low weight children are in the form of spatial error.

Conclusion Social deprivation impacts the health of different populations, and this influence exhibits correlation and interaction across various regions. Therefore, it is necessary for governments to develop policies, particularly those aimed at enhancing the equality of public health services, to address the imbalance in regional development, allocate resources scientifically, and narrow the gap in economic, social, and healthcare development across regions.

Keywords Social Deprivation, Health Outcomes, Spatial Regression, China

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Introduction

Health inequality is a topical topic of international concern [1, 2]. China is the largest developing country, and health inequality still exists. Despite significant breakthroughs in China's level of medical services, the level of health welfare among residents still diverges between urban and rural areas, with urban dwellers taking the lead [3]. To reduce this health welfare gap, the *Healthy China Initiative (2019–2030)* was launched by the Chinese government in 2019, which explicitly proposes to achieve basic health equality.

The main factors affecting health equity can be summarized into two aspects. First is income inequality. Economic status is positively correlated with health levels in both developed countries and developing countries [4, 5]. Second, social inequality must be considered [6]. Some potential social determinants, such as housing environment, immigration [7], education [8], and health literacy, impact the health level of the population. Therefore, the concept of "social deprivation" has been introduced in recent years academically to assess how social factors affect health outcomes.

"Social deprivation" describes the condition where individuals or groups entirely lack, or do not possess sufficient living conditions due to unfair treatment [9]. Empirical research has recognized that social deprivation has a crucial impact on health outcomes [10, 11]. Chinese scholars have also explored the relationship between social deprivation and health outcomes. In China, research has shown a close correlation between social deprivation and non-communicable chronic diseases [12]. Researchers found spatial association between type 2 diabetes prevalence and neighbourhood deprivation in Zhejiang, China [13]. Scholars further propose that social deprivation in rural areas of China in 2010 may impact public health, and this impact exhibits spatial dependence [14].

However, research on the relationship between social deprivation and health outcomes is inadequate in China. On the one hand, compared with foreign scholar's research on the relationship between social deprivation and health, recent studies on social deprivation in China are mostly limited to specific provinces or cities, and nationwide studies are relatively scarce. On the other hand, previous studies may be inapplicable to explain the current relationship between social deprivation and health outcomes in China. It is worth noting that with the improvement of urbanization levels in China, by 2020, the permanent urbanization rate reached 63.89%. Accompanied by large-scale urbanization, a large number of rural residents migrated to cities, enjoying many advantages brought about by urbanization [15], such as more opportunities to access education, work, and healthcare, which gradually narrows the living standard gap between urban and rural areas. And it has been shown that the level of urbanization can have a significant negative impact on public health outcomes [16]. Consequently, it is necessary to provide evidence of whether social deprivation is changing in China and whether the association between social deprivation and public health outcomes has changed.

The study puts the following questions: more than a decade has passed, compared to studies mainly concentrated in rural areas ten years ago, have nationwide social deprivation situations, including cities and rural areas, changed? Has its impact on health intensified? Does the relationship with health still exhibit spatial dependence? Is there mutual influence between adjacent areas?

Based on these questions, this paper aims to conduct a deep analysis of the relationship between the health status of populations in 31 provinces and autonomous regions in China and social deprivation using the latest census data. Firstly, it will assess the state of social deprivation in China and explore the spatial distribution of social deprivation in 31 provinces. Secondly, through the spatial regression model, quantify the relationship between social deprivation and the health of the population in each province, and analyze the impact of social deprivation on population health.

Literature review

Concept of social deprivation

"Social deprivation" is defined as the obstacles and limitations individuals encounter in achieving a high-quality life when they fall into disadvantageous positions in domains such as material resources, living environment, educational opportunities, employment prospects, and community services [17]. This concept can be divided into two categories: absolute deprivation and relative deprivation.

Absolute deprivation refers to the deprivation individuals experience due to lack or loss of certain resource(s) necessary for basic survival needs (such as food, clothing, and shelter). Absolute social deprivation reveals the multiple disadvantages of material resources and quality of life, which are significant factors leading to poverty. Poverty is inherently connected to the concept of deprivation. Poverty caused by lack of material resources is unidimensional, but deprivation is multidimensional and a reflection of poverty [18]. With the deepening of poverty governance research, it has been a dominant trend to shift the poverty perspective from a single dimension of income poverty to a multi-dimensional deprivation perspective. The approach of using multidimensional social deprivation to identify relative poverty has been widely used.

In China's academic environment, the application of absolute social deprivation is widespread. It plays a key role in discussing socially concerned issues like land loss of farmers [19], medical security for the poor [20], and human resource allocation in healthcare institutions [21]. Now, Chinese scholars pay more attention to the study of relative poverty based on multidimensional deprivation, such as the identification of relative poverty and the factors affecting poverty [22, 23], the study of the effect of medical insurance in reducing poverty [24], and the mechanism and path of social factors on poverty reduction [25, 26].

In contrast, relative deprivation focuses more on revealing the psychological gap and resulting sense of deprivation generated when comparing oneself with those who are socio-economically superior [27]. It can be observed that while absolute deprivation emphasizes the objective degree of deprivation of material and resources, relative deprivation highlights individuals' sense of dissatisfaction and deprivation on an emotional level.

In this paper, absolute deprivation is chosen as the research tool to deeply explore how the deprivation of material conditions and social resources impacts public health.

Measurement of social deprivation

Currently, there is no standardized indicator for measuring social deprivation, as well as no widely accepted and used evaluation system exists. These indicators usually present different characteristics influenced by the characteristics of the research area itself. For instance, Thompson's social deprivation index includes family activities, social support and integration, social creation, and education [9]. In 2000, British scholars constructed a more comprehensive social deprivation index, including income, employment, health deprivation, education, housing, and service barriers [28]. In Boston, a social deprivation index was established that includes neighborhood deprivation level, income, education, ethnicity, marital status, age, and fertility conditions [29]. Similarly, the multiple social deprivation index of Auckland, New Zealand, has achieved notable success. This index covers employment, income, crime, housing, health, education, and geographic access [30]. China also borrows foreign methods of measuring social deprivation and, based on its national conditions, carries out in-depth exploration of domestic social deprivation evaluation. In Chinese cities, the social deprivation index is measured from five areas: income, education, employment, housing, and population structure [15]. Shenzhen's social deprivation index includes income, employment, education, population structure, and housing [31]. It can be seen that although the domains of indicator measurement in different environments and situations are not exactly the same, they basically all include the five core aspects of income, education, employment, housing, and population structure.

Application of social deprivation in the health field

The concept of social deprivation is widely applied in the health field. Originating from sociology, the initial research focus was on social poverty issues [32], social satisfaction, and social fairness [33]. Subsequently, scholars found a significant correlation between poverty and health conditions. For example, poor levels of social deprivation leads to differences in regional health and welfare levels [34]. Therefore, social deprivation is also used to study issues in the health sector. On the one hand, the risk of disease occurrence is concerned. For instance, Japanese scholars found that levels of economic and social deprivation increased the risk of viral hepatitis B and C infection [35]. Socioeconomic deprivation is recognized as an independent risk factor for kidney disease [36]. Deprivation is associated with an increased risk of developing chronic diseases [37]. On the other hand, the effects on health damage have been widely studied. German scholars have concluded that there is a significant association between regional deprivation and mortality and morbidity [38]. The social deprivation index explains changes in life expectancy at birth [39]. People who were materially deprived and socially deprived have a higher risk of dying from diseases such as cancer, heart attack and stroke [40].

Chinese scholars have also introduced the concept of absolute social deprivation to study health issues. On the one hand, scholars have focused on the relationship between social deprivation and physical health. For example, a higher risk of death exists among highly deprived populations [41]. Populations with lower neighborhood deprivation levels are less likely to suffer from non-communicable chronic diseases [12]. Similarly, the degree of social deprivation is proportional to the incidence rate of liver cancer [31]. Moreover, there is a relationship between social deprivation and rural public health [14]. There is a positive correlation between social deprivation and cancer mortality in Hong Kong [42]. Social deprivation is positively associated with secondhand smoke exposure among urban male residents [43]. On the other hand, academics have also explored the relationship between absolute social deprivation and mental health. For example, deprivation is positively connected to anxiety and stress [44]. Multidimensional energy deprivation is positively associated with depression among Chinese older adults [45]. There is a negative relationship between material deprivation and children's life satisfaction [46].

However, compared to foreign studies on the relationship between social deprivation and health, there is less research on the relationship between absolute social deprivation and public health outcomes in China, and such studies still lack strong evidence. Recent studies on social deprivation in China are mostly limited to specific provinces or cities, and nationwide studies are relatively scarce. Moreover, the few existing studies mainly used rural data from 14 years ago. Therefore, it is of great significance to explore the impact of social deprivation on health at the national level. This can not only supplement research data at the national level but also update research data in recent years.

Methods and data

Formulating a social deprivation index for China

The steps to construct a social deprivation index include: (1) selecting indices for measuring social deprivation; (2) normalizing data; (3) using entropy weighting method, variation coefficient method, and Criteria Importance Through Intercrieria Correlation (CRITIC method) to calculate the weight of each index and derive the overall index based on the social deprivation index formula. Additionally, the principal component analysis method is used to construct the social deprivation index. The specific steps are as follows.

Based on previous studies and considering data accessibility, this paper selects 20 indices from five aspects: income, education, employment, housing, and population structure. A panel composed of four experts in social science or public health judged the applicability of each index based on four criteria: scale appropriateness, scientific validity, usability, and recognizability. They rated them into four levels: Level 1 (very unsuitable), Level 2 (unsuitable), Level 3 (suitable), and Level 4 (very suitable). Finally, the average scores of these indices were calculated, retaining those with higher scores. Based on the experts' recommendations, 14 social deprivation indices were finally retained (Table 1). The original data of these indices come from the 7th National Census of China in 2020. Considering data accessibility, only data from 31 provincial administrative regions in China were analyzed.

This study uses factor analysis to reduce the dimensions of social deprivation. As income, employment, and population structure fields only contain one or two indices, no dimension reduction is carried out for these fields. However, education and housing fields undergo dimension reduction through factor analysis. Firstly, in the education field, one reliable main component that explains 75.058% of the total variance was extracted based on the criterion of eigenvalues greater than 1, correlating most with IR, NFE, and BEC. Secondly, in the housing field, two reliable main components were

Table 1 Indicators of Social Deprivation in China

Domain	Indicators	Unit	Definition
Income	Engel's coefficient (EC)	%	Proportion of family income which is spent on food
	Per capita disposable income (PCDI)	yuan	Per capital disposable income of national households
Employment	Proportion of unemployed population (PUP)	%	Proportion of unemployed population in national areas
	Percentage of agricultural population (PAP)	%	Ratio of the population who are employed in agricultural industry to the employed population in national areas
Education	Illiteracy rate (IR)	%	Illiteracy rate in national areas
	Proportion of population receiving not fundamental education (NFE)	%	The age of population in this index is above 6 years in national areas
	Proportion of population with degree below elementary school (BEC)	%	The age of population in this index is above 6 years in national areas
Housing conditions	Proportion of households without kitchens (WOK)	%	Proportion of households without kitchens in national areas
	Proportion of households without piped water (WOW)	%	Proportion of households without piped water in national areas
	Proportion of households without bathing facilities (WOB)	%	Proportion of households without bathing facilities in national areas
	Proportion of households without toilets (WOT)	%	Proportion of households without toilets in rural areas
Housing area	Per capita housing construction area (HCA)	m^2/person	Per capita housing construction area in rural areas
Demographic structure	Proportion of households composed of one person (OP)	%	Proportion of households composed of one person in rural areas
	Proportion of widows (PW)	%	Proportion of women whose spouses have died in rural areas

extracted, where the first explains 62.166% of the variance, correlating most with WOK, WOW, WOB, WOT, and the second explains 22.479% of the variance, correlating most with HCA. Consequently, the original housing field is split into two fields: housing condition and housing area.

To further enhance the accuracy of the social deprivation index and avoid subjectivity, this paper adopts three objective weight determination methods—the entropy weighting method, variation coefficient method, and CRITIC method—to calculate the social deprivation index. Firstly, the basic idea of the entropy method is to reflect the distinguishing capability of each index on evaluation objects from the perspective of index entropy. The smaller the entropy of an index, the more orderly its sample data, the greater the difference among sample data, and the greater the distinguishing capability of the index on evaluation objects, so the corresponding weight is larger [47]. Secondly, the variation coefficient method determines the weight of the index by calculating the degree of difference in each index data. The greater the internal data difference of the index, the greater the distinguishing role of the index on evaluation objects, and the greater the weight allocation value [48]. The coefficient of variation is defined as the ratio of standard deviation σ to average μ. The weight of the index is measured by the ratio of the coefficient of variation of the index to the sum of the coefficients of variation [49]. Thirdly, the CRITIC method measures the objective weight between various indices through comparing intensity and conflict. The standard deviation represents the comparison intensity of the index. The larger the standard deviation, the greater the value difference between schemes. Although the correlation coefficient is a quantitative indicator of conflict, conflicts decrease with an increase in the correlation coefficient [50].

The following are steps for defining weights: a. Normalize the indices using Eq. (1). b. Calculate the value of information entropy through Eq. (2). c. Calculate the weight of the entropy method using Eq. (3). d. Calculate the weight of the variation coefficient method using Eq. (4). e. Calculate the information carrying amount C_j of the CRITIC method using Eq. (5) and calculate its weight using Eq. (6).

$$X'_{ij} = \begin{cases} (X_{ij} - minX_{ij})/(maxX_{ij} - minX_{ij})\ positive \\ (maxX_{ij} - X_{ij})/(maxX_{ij} - minX_{ij})\ negative \end{cases} \tag{1}$$

where X'_{ij} represents the normalized index. Standardization formulas are chosen according to the direction of the index; larger positive index values indicates higher deprivation, and larger negative index values indicates lower deprivation.

where X'_{ij} is the normalized value of the indicator, $maxX_{ij}$ and $minX_{ij}$ are maximal value and minimal value of indicator i for all provinces.

$$e_j = -\frac{1}{\ln(n)}\sum_{i=1}^{n} Y_{ij}\ln \mathrm{Y_{ij}},\ \mathrm{Y_{ij}} = \frac{\mathrm{X}'_{ij}}{\sum_{\mathrm{i}=1}^{n} X'_{ij}} \tag{2}$$

Y_{ij} is the magnitude of the variance; X'_{ij} *is* the coefficient after normalization; e_j is the information entropy.

$$w_j = \frac{(1 - e_j)}{\sum_{j=1}^{m}(1 - e_j)} \tag{3}$$

The coefficient variation is defined as the ratio of the standard deviation σ to the mean μ.

$$w_j = \frac{\sigma_j}{\mu_j}/\sum\frac{\sigma_j}{\mu_j} \tag{4}$$

$$C_j = \sigma_j\sum_{i=1}^{m}(1 - r_{ij}) \tag{5}$$

where σ_j represents the standard deviation of index j, representing the comparison intensity of the index. r_{ij} is used to represent the Pearson correlation coefficient, which is a linear correlation coefficient. Therefore, the larger the information load, C_j the more information the index contains. The weight calculation formula is as follows:

$$w_j = \frac{C_j}{\sum_{j=1}^{b} C_j} \tag{6}$$

The social deprivation value calculation formula is as follows:

$$SD_j = \sum_{i=1}^{n} w_j \times X'_{ij} \tag{7}$$

Next, the social deprivation value is calculated using the principal component analysis method. The principal component analysis method is a commonly used method to calculate the social deprivation index [17]. Its basic principle is to use the idea of dimension reduction to convert a group of related indices into another group of unrelated comprehensive indices [51], i.e., main components, and then calculate the social deprivation score through the formula. The steps for calculating the social deprivation value using the principal component analysis method are as follows: 1. Normalize the index data using Eq. (1). 2. Calculate the main component scores using Eq. (8). 3. Calculate the social deprivation score using Eq. (9).

$$F_i = \sum_{m=1}^{n}\alpha_j \times X_j \tag{8}$$

where α_j is the loading factor of index j; X_j is the standardized value of index j; n is the total number of observations.

$$SD_j = \sum_{k=1}^{p} \alpha_k \times F_i \tag{9}$$

where α_k is the variance percentage of the k_{th} component, p is the number of main components, and F_i is the score of the i_{th} main component of deprivation. The social deprivation scores can refer to Table 4.

Index selection for public health outcomes

To reflect the health status of the Chinese population comprehensively, this research selected the incidence rate of Class A and B infectious diseases, mortality rate of Class A and Class B infectious diseases, prevalence rate of low weight children under 5 years old, maternal mortality rate, average life expectancy, and proportion of healthy elderly (Table 2). The corresponding data come from the *China Health Statistics Yearbook* published in 2021.

Infectious diseases, due to their characteristics, can potentially harm public health on a large scale once they break out. In China, according to different transmission methods, transmission speeds, and harms to humans of each disease, 35 acute and chronic communicable diseases with high national incidence rates, large epidemic areas, and serious damages are classified into classes A, B, and C, and are included in legal management. The incidence rate and mortality rate of Class A and Class B infectious diseases reflect the national attention to people's health safety and also show China's ability to prevent and control these diseases.

The prevalence rate of low-weight children reflects the survival status of children. Malnutrition is the main cause of low weight in children, and about 45% of deaths among children under 5 years worldwide are related to malnutrition, mainly occurring in low- and middle-income countries and regions [52]. Lack of nutrition will reduce children's immunity, increase morbidity, and further increase economic burdens on families and societies.

Maternal mortality rate can reflect the state of a country's healthcare system. Improving public health service capabilities and medical service levels and quality can help lower maternal mortality rates. Average life expectancy is an important index that measures a society's economic development level and healthcare service level, and it is also one of the three core indices of the UN Human Development Index. The proportion of healthy elderly reflects the quality of life of the elderly and the social security for the elderly group. Statistical descriptions can be seen in Table 3.

Model selection for social deprivation and health outcomes

Previous research has already found that health outcomes often show spatial autocorrelation at geographical scales. In this context, traditional OLS might be limited in identifying factors affecting health outcomes. To avoid estimation bias caused by spatial dependency, this research attempts to select the most suitable model from OLS models and spatial regression models to analyze the impact of social deprivation on the national population's health. Two types of spatial models are included in the regression: spatial lag model (SLM) as shown in Eq. (10), and the spatial error model (SEM) as shown in Eq. (11). The spatial lag regression model explains the impact of space diffusion effect generated by dependent variables of neighboring regions on dependent variables, while the spillover effect of random shock conduction due to spatial regional differences among variables is explained by spatial error regression. In this study, a first-order queen contiguity weight is used as the spatial weight.

$$y = \beta x + \lambda W_y + \mu \tag{10}$$

$$y = \beta x + \mu,\ \mu = \rho W_\mu + \nu \tag{11}$$

Table 2 Selected indicators of public health

	Indicator	Unit	Definition
Health	Incidence rate of Class A and B infectious diseases (IID-A&B)	1/100,000	It refers to the number of cases of legally reported infectious diseases of categories A and B per 100,000 population in a certain region in a certain year
	Mortality rate of Class A and Class B infectious diseases (MRID-A&B)	1/100,000	It refers to the number of deaths from legally reported infectious diseases of categories A and B per 100,000 population in an area in a given year
	Prevalence rate of low weight children (PR-LWC)	%	Percentage of children under 5 years of age whose weight is less than the median weight for their age group minus 2 standard deviations from the median weight for children of the same age group as a percentage of the total number of children under 5 years of age who are examined
	Maternal mortality rate (MMR)	1/100,000	Maternal mortality rate in different provinces
	Average life expectancy (ALE)	years	The average time a person is expected to live based on the year of his/her birth
	Proportion of healthy elderly (PHE)	%	Proportion of healthy elders whose age is above 60 years in national areas

Table 3 Statistical description for the indicators of social deprivation and public health ($N = 31$)

	Variable	Obs	Mean	Std.Dev	Min	Max
Social Deprivation	EC	31	30.352	3.499	21.525	39.607
	PCDI	31	32,086.38	12,661.02	20,35.10	72,232.40
	PUP	31	3.290	0.580	2.100	4.600
	PAP	31	13.131	6.136	1.085	25.964
	IR	31	4.279	4.959	0.890	28.080
	NFE	31	67.852	8.458	38.894	81.041
	BEC	31	8.201	4.937	3.671	30.821
	WOK	31	4.691	4.617	0.606	23.197
	WOW	31	9.716	7.422	1.171	36.577
	WOB	31	15.880	15.715	2.653	70.283
	WOT	31	4.816	4.806	0.613	23.499
	HCA	31	40.329	6.161	32.280	54.960
	OP	31	25.288	3.630	19.988	33.224
	PW	31	0.338	0.051	0.227	0.425
Health Result	IID-A&B	31	199.580	80.217	80.800	376.800
	MRID-A&B	31	1.712	2.092	0.280	8.510
	PR-LWC	31	1.059	0.729	0.180	3.310
	MMR	31	11.616	8.042	3.900	47.900
	ALE	31	78.377	2.154	72.190	82.550
	PHE	31	52.554	7.752	36.004	65.013

Abbreviation: *EC* Engel's coefficient, *PCDI* Per capita disposable income, *PUP* Proportion of unemployed population, *PAP* Percentage of agricultural population, *IR* Illiteracy rate, *NFE* Proportion of population receiving not fundamental education, *BEC* Proportion of population with degree below elementary school, *WOK* Proportion of households without kitchens, *WOW* Proportion of households without piped water, *WOB* Proportion of households without bathing facilities, *WOT* Proportion of households without toilets, *HCA* Per capita housing construction area, *IID-A&B* Incidence rate of Class A and B infectious diseases, *MRID-A&B* Mortality rate of Class A and Class B infectious diseases, *PR-LWC* Prevalence rate of low weight children, *MMR* Maternal mortality rate, *ALE* Average life expectancy, PHE Proportion of healthy elderly

where y is the dependent variable, x is the independent variable, β is the coefficient of the independent variable, W is the spatial weight, λ is the spatial lag coefficient, and ρ is the spatial error coefficient.

Several spatial correlation test methods have been adopted to evaluate the spatial correlation and relevance of spatial regression models in observations, including Moran's I-Error, LM-Error, robust LM-Error, LM-Lag, and robust LM-Lag. Moran's I-Error is a method to test the spatial correlation of residuals in OLS models. The LM test is used to test model residuals and spatial autoregressive effects. Specifically, LM-Error and robust LM-Error statistics are used to verify the spatial association of model residuals, while LM-Lag and robust LM-Lag statistics are used to verify the spatial autoregressive effect of models.

Firstly, Moran's I test is performed on the dependent variable to determine whether there are spatial distribution states such as aggregation, discrete or random distribution. Then the spatial lag model needs to be judged based on the Lagrange Multiplier (LM) test. Secondly, the LM test is performed. If both LM-Error and LM-Lag are insignificant, OLS is retained. If LM-Error is significant but LM-Lag is not, the spatial error model is selected. If LM-Lag is significant but LM-Error is not, the spatial lag model is selected. If both the robust LM-Lag and robust LM-Error of the model are significant ($p < 0.1$), the model with the larger test value is selected [53]. A model with larger R^2 and log likelihood values and smaller Akaike info criterion (AIC) implies better performance is more applicable for subsequent analysis. Model judgment (including SEM, SLM, OLS), health outcomes Moran's I, and spatial weight matrix were performed in GeoDa1.16. The model selection process can be seen in Fig. 1.

Results

Social deprivation in China

Depending on the different methods used to determine the social deprivation index, four approaches—$SD_{Entropy}$, SD_{CV}, SD_{CRITIC}, and SD_{PCA}—are employed to calculate social deprivation values (Table 4). To test whether the results derived from these four calculation methods are consistent, binary regression is used to verify the social deprivation scores calculated through different methods (Table 5). Pearson correlation analysis reveals the hidden correlation strength between the four calculation methods. After conducting pairwise correlation tests for social deprivation values calculated by the four methods,

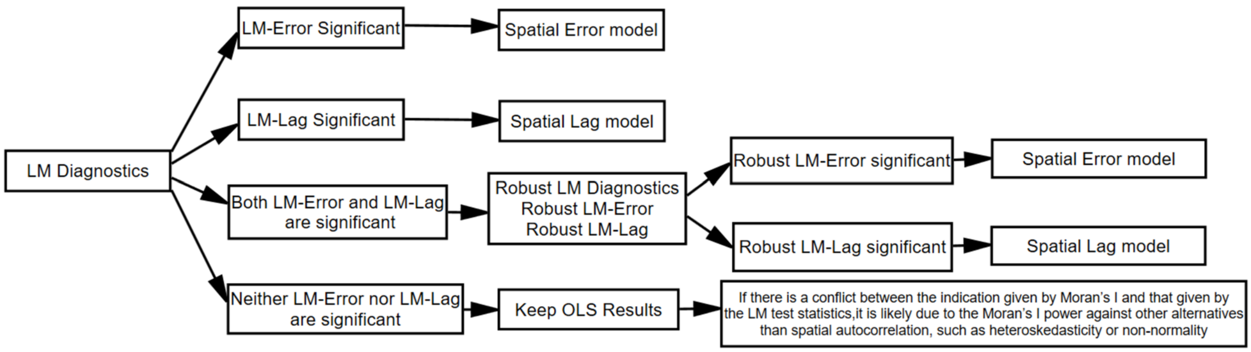

Fig. 1 Spatial regression decision process

Table 4 Corresponding values of social deprivation

District	$SD_{Entropy}$	SD_{CV}	SD_{CRITIC}	SD_{PCA}
Beijing	0.170	0.179	0.268	5.195
Tianjin	0.145	0.181	0.334	7.499
Hebei	0.195	0.234	0.389	11.791
Shanxi	0.347	0.364	0.477	16.205
Inner Mongolia	0.396	0.418	0.542	18.098
Liaoning	0.317	0.360	0.578	15.118
Jilin	0.272	0.311	0.517	13.987
Heilongjiang	0.309	0.347	0.559	14.807
Shanghai	0.171	0.197	0.341	6.102
Jiangsu	0.146	0.18	0.306	8.58
Zhejiang	0.219	0.241	0.344	10.109
Anhui	0.222	0.262	0.391	13.236
Fujian	0.204	0.247	0.393	11.476
Jiangxi	0.166	0.206	0.321	11.494
Shandong	0.195	0.235	0.379	11.879
Henan	0.19	0.225	0.348	11.60
Hubei	0.179	0.225	0.391	11.045
Hunan	0.201	0.244	0.396	12.493
Guangdong	0.188	0.228	0.387	9.463
Guangxi	0.223	0.271	0.428	13.979
Hainan	0.273	0.318	0.462	15.616
Chongqing	0.207	0.266	0.498	11.345
Sichuan	0.287	0.343	0.541	16.016
Guizhou	0.325	0.363	0.492	16.901
Yunnan	0.327	0.368	0.513	17.111
Tibet	0.914	0.882	0.736	37.645
Shaanxi	0.255	0.289	0.435	12.575
Gansu	0.374	0.406	0.545	18.577
Qinghai	0.452	0.459	0.500	21.09
Ningxia	0.197	0.238	0.383	11.087
Xinjiang	0.183	0.227	0.385	11.739

SDEntropy, SDCV, SDCRITIC and SDPCA are the social deprivation estimated by Entropy method, Coefficient variation method(CV), Criteria importance though intercrieria correlation(CRITIC) and principle component analysis (PCA)

it is found that all Pearson correlation coefficients are significant at the 0.01 level (two-tailed), and all Pearson correlation coefficients exceed 0.7. The Pearson correlation coefficients between entropy weighting method and variation coefficient method, CRITIC method, principal component analysis method are all significant at the 0.01 level (two-tailed). Among them, the Pearson correlation coefficient between entropy weighting method and variation coefficient method is as high as 0.992, demonstrating a strong correlation. At the same time, there is a strong correlation between entropy weighting method and CRITIC method, entropy weighting method and principal component analysis method, CRITIC method and variation coefficient method, CRITIC method and principal component analysis method, variation coefficient method, and principal component analysis method.

Therefore, despite differences in the social deprivation values derived from these four methods, their results show consistency. In China, social deprivation exhibits evident heterogeneity (see Fig. 2). Generally, regions with higher degrees of social deprivation in China are mainly concentrated in the west and northeast, while areas with lower degrees of social deprivation are mostly located in the central part and coastal areas in the east.

Model selection for social deprivation and population health

The Moran's I test statistic of the dependent variable (health outcomes) is significant. The Moran's I values of incidence rate of Class A and B infectious diseases, mortality rate of Class A and Class B infectious diseases, prevalence rate of low weight children, maternal mortality rate, average life expectancy, and proportion of healthy elderly are 0.487, 0.283, 0.396, 0.325, 0.341, 0.519, respectively. Therefore, the null hypothesis of random distribution of samples in the study area is rejected. Simultaneously, the global Moran's I index being greater than 0 indicates the presence of high-high and low-low

Table 5 Correlation test for the four values of social deprivation

(a) Pearson correlation between Entropy and Coefficient variation method			
		$SD_{Entropy}$	SD_{CV}
$SD_{Entropy}$	Pearson correlation	1	0.992
	Sig(2-tailed)		< 0.001
	N	31	31
SD_{CV}	Pearson correlation	0.992	1
	Sig(2-tailed)	< 0.001	
	N	31	31
(b) Pearson correlation between Entropy and CRITIC method			
		$SD_{Entropy}$	SD_{CRITIC}
$SD_{Entropy}$	Pearson correlation	1	0.704
	Sig(2-tailed)		< 0.001
	N	31	31
SD_{CRITIC}	Pearson correlation	0.704	1
	Sig(2-tailed)	< 0.001	
	N	31	31
(c) Pearson correlation between Entropy and PAC method			
		$SD_{Entropy}$	SD_{PCA}
$SD_{Entropy}$	Pearson correlation	1	0.929
	Sig(2-tailed)		< 0.001
	N	31	31
SD_{PCA}	Pearson correlation	0.929	1
	Sig(2-tailed)	< 0.001	
	N	31	31
(d) Pearson correlation between Coefficient variation and CRITIC method			
		SD_{CV}	SD_{CRITIC}
SD_{CV}	Pearson correlation	1	0.768
	Sig(2-tailed)		< 0.001
	N	31	31
SD_{CRITIC}	Pearson correlation	0.768	1
	Sig(2-tailed)	< 0.001	
	N	31	31
(e) Pearson correlation between Coefficient variation and PAC method			
		SD_{CV}	SD_{PCA}
SD_{CV}	Pearson correlation	1	0.954
	Sig(2-tailed)		< 0.001
	N	31	31
SD_{PCA}	Pearson correlation	0.954	1
	Sig(2-tailed)	< 0.001	
	N	31	31
(e) Pearson correlation between CRITIC and PAC method			
		SD_{CRITIC}	SD_{PCA}
SD_{CRITIC}	Pearson correlation	1	0.746
	Sig(2-tailed)		< 0.001
	N	31	31
SD_{PCA}	Pearson correlation	0.746	1
	Sig(2-tailed)	< 0.001	
	N	31	31

spatial autocorrelation among the sample group, effectively demonstrating the necessity of using spatial econometric analysis.

Table 6 shows the spatial autocorrelation results of the spatial regression. To eliminate possible estimation bias of OLS models due to spatial effects and compare the effectiveness of different models, a spatial diagnosis was carried out on the OLS model. In Table 7, OLS, SEM, and SLM models were compared.

Table 7 demonstrates the model performance of spatial regression and OLS. Comparing OLS, SEM, and SLM models, some models chose OLS, while others opted for spatial regression models. In some models, the significant Moran's I-Error indicates that residuals in OLS display a spatial autocorrelation pattern, which violates the basic assumption of homoscedasticity [54]. Meanwhile, the OLS model R^2 are relatively low and AIC are relatively high. For these models, the R^2 of the spatial regression model far exceeds the R^2 of the OLS model, and AIC of the spatial regression model is lower than AIC of the OLS model. It suggests that the spatial regression model can better explain the relationship between social deprivation and health outcomes.

Ultimately, according to the analysis above, the incidence rate of Class A and Class B infectious diseases and $SD_{Entropy}$, SD_{CV}, SD_{PCA} choose the spatial lag model. the mortality rate of Class A and Class B infectious diseases and $SD_{Entropy}$, SD_{CV} choose the spatial error model. The prevalence rate of low weight children with $SD_{Entropy}$, SD_{CV}, SD_{PCA} chooses the spatial error model. Maternal mortality rate with $SD_{Entropy}$, SD_{CV} chooses the spatial lag model. Average life expectancy with $SD_{Entropy}$, SD_{CV} chooses the spatial lag model. The proportion of healthy elderly with all four models of social deprivation opts for the spatial lag model. The chosen best models are presented in bold in Table 7.

Relationship between social deprivation and national health status

Table 8 shows the relationship between social deprivation and the health status of the Chinese population. Firstly, the best model indicates that the independent variable coefficients between social deprivation and incidence rate of Class A and B infectious diseases, mortality rate of Class A and B infectious diseases, maternal mortality rate, average life expectancy, and proportion of healthy elderly are significant. Different social deprivation evaluation methods do not change the sign of social deprivation coefficients, and the measurement results are basically consistent. Therefore, it can be concluded that different calculation methods have a small impact on the sensitivity of the relationship between social deprivation and population health status.

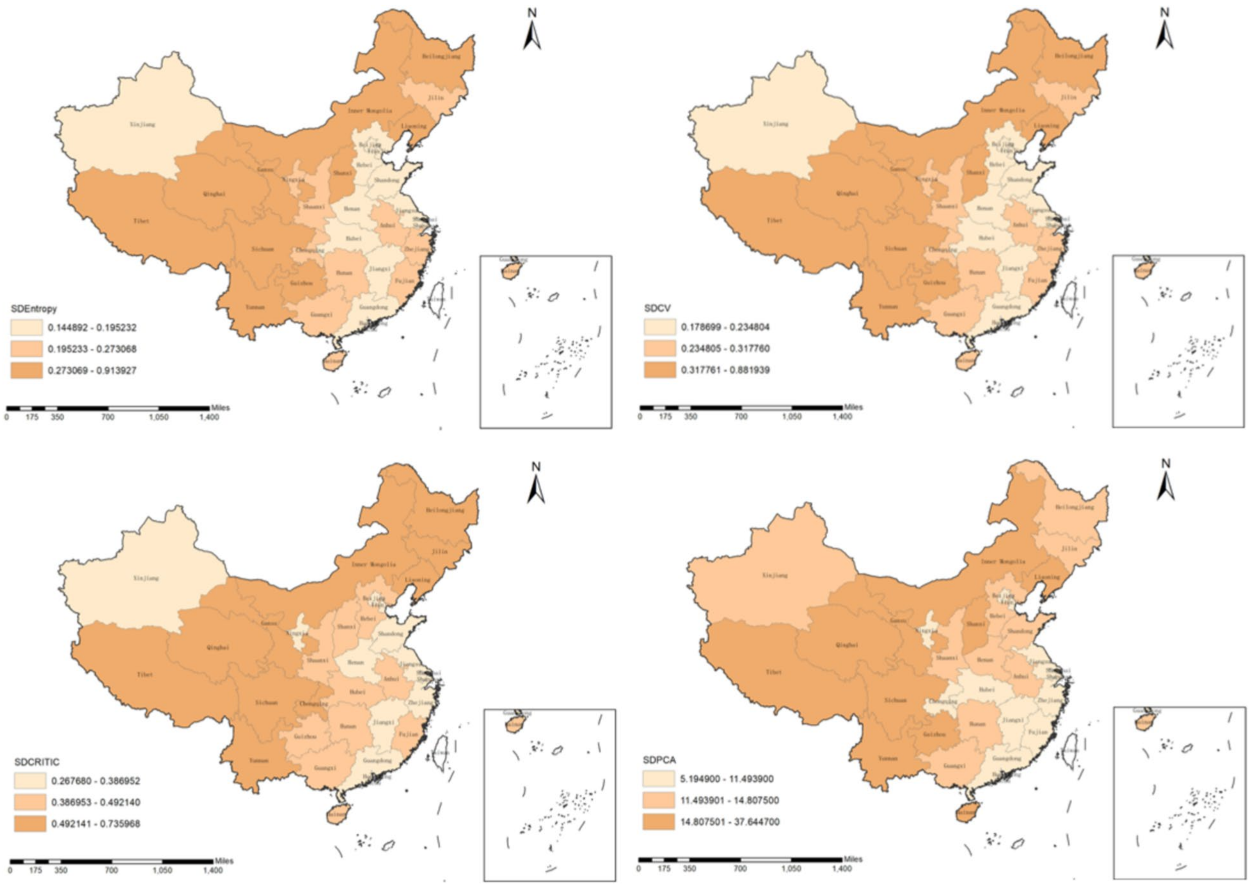

Fig. 2 Social deprivation distribution in China estimated by different weight determination methods

Secondly, social deprivation is positively correlated with the incidence rate of Class A and B infectious diseases, prevalence rate of low weight children, and maternal mortality rate. This implies that regions with high degrees of social deprivation often accompany high incidence rates of infectious diseases, prevalence rates of low weight children, and maternal mortality rates. Meanwhile, there exists a negative correlation between social deprivation and mortality rates of infectious diseases, average life expectancy, proportion of healthy elderly. This finding indicates that in areas with lower degrees of social deprivation, average life expectancy is longer and the proportion of healthy elderly is higher.

In addition, in part of regression models for influence between social deprivation and incidence rate of Class A and B infectious diseases, social deprivation and proportion of healthy elderly, social deprivation and maternal mortality rate, social deprivation and average life expectancy are in the form of spatial lag. It indicates that the values of variables in certain provinces are directly influenced by the corresponding status of these indicators in neighboring provinces. Simultaneously, in part of regression models for impact between social deprivation and prevalence rate of low weight children is in form of spatial error. This implies that social deprivation has a spatial spillover effect on the prevalence rate of low weight children and mortality rate of Class A and B infectious diseases, meaning that other influencing factors of the prevalence rate of low weight children and mortality rate of Class A and B infectious diseases in certain region can affect the prevalence rate of low weight children and mortality rate of Class A and B infectious diseases in adjacent areas through spatial transmission mechanisms.

Discussion

Spatial heterogeneity of social deprivation in China

Due to the differences in the selection of social deprivation indicators, the results of this paper cannot be compared with other countries. Compared with the study on rural social deprivation in China in 2010, the social deprivation situation in most provinces has been alleviated. This could be attributed to a more developed economy today and year-by-year improvements in social welfare. Additionally, with the progression of urbanization, this

Table 6 Spatial autocorrelation in spatial regression models

Y	X	Moran's I-Error	P	LM-Lag	P	R-LM-Lag	P	LM-Error	P	R-LM-Error	P
IID-A&B	$SD_{Entropy}$	0.424	< 0.001	12.199	< 0.001	1.279	0.258	10.950	< 0.001	0.031	0.861
	SD_{CV}	0.413	< 0.001	11.604	0.001	1.245	0.264	10.410	0.001	0.051	0.82
	SD_{CRITIC}	0.448	< 0.001	12.227	0.001	0.212	0.646	12.243	< 0.001	0.228	0.633
	SD_{PCA}	0.382	< 0.001	9.856	0.001	1.147	0.284	8.867	0.003	0.158	0.691
MRID-A&B	$SD_{Entropy}$	0.324	0.001	5.648	0.017	1.869	0.171	6.406	0.011	2.628	0.104
	SD_{CV}	0.311	0.002	5.407	0.020	2.218	0.136	5.905	0.015	2.716	0.099
	SD_{CRITIC}	0.267	0.005	4.587	0.032	1.766	0.184	4.349	0.037	1.528	0.216
	SD_{PCA}	0.285	0.004	4.922	0.027	2.720	0.099	4.945	0.026	2.744	0.098
PR-LWC	$SD_{Entropy}$	0.325	0.001	5.572	0.018	0.353	0.552	6.426	0.011	1.207	0.272
	SD_{CV}	0.327	0.001	5.505	0.019	0.347	0.556	6.499	0.011	1.340	0.247
	SD_{CRITIC}	0.320	0.001	5.453	0.020	0.523	0.467	6.229	0.013	1.305	0.253
	SD_{PCA}	0.347	< 0.001	5.321	0.021	0.759	0.384	7.353	0.007	2.790	0.095
MMR	$SD_{Entropy}$	0.027	0.550	4.173	0.041	4.638	0.031	0.045	0.832	0.510	0.475
	SD_{CV}	0.066	0.342	2.946	0.086	2.734	0.098	0.267	0.605	0.055	0.813
	SD_{CRITIC}	0.212	0.021	1.443	0.229	< 0.001	0.987	2.746	0.098	1.302	0.254
	SD_{PCA}	0.130	0.128	1.487	0.223	0.715	0.398	1.032	0.310	0.260	0.610
ALE	$SD_{Entropy}$	0.098	0.225	3.548	0.060	4.060	0.044	0.587	0.444	1.099	0.294
	SD_{CV}	0.068	0.332	2.951	0.086	3.905	0.048	0.286	0.593	1.239	0.266
	SD_{CRITIC}	0.142	0.092	2.555	0.110	1.536	0.215	1.220	0.269	0.201	0.653
	SD_{PCA}	-0.024	0.855	1.771	0.183	3.653	0.056	0.035	0.852	1.917	0.166
PHE	$SD_{Entropy}$	0.251	0.011	10.594	0.001	8.688	0.003	3.840	0.050	1.934	0.164
	SD_{CV}	0.247	0.012	10.106	0.001	7.918	0.005	3.715	0.054	1.527	0.217
	SD_{CRITIC}	0.247	0.009	7.995	0.005	4.968	0.026	3.723	0.053	0.696	0.404
	SD_{PCA}	0.277	0.005	10.039	0.002	5.781	0.016	4.680	0.030	0.421	0.516

SDEntropy, SDCV, SDCRITIC and SDPCA are the social deprivation estimated by Entropy method, Coefficient variation method, Criteria Importance Though Intercrieria Correlation (CRITIC) and principle component analysis (PCA)

IID-A&B Incidence rate of Class A and B infectious diseases, MRID-A&B Mortality rate of Class A and Class B infectious diseases, PR-LWC Prevalence rate of low weight children, MMR Maternal mortality rate, ALE Average life expectancy, PHE Proportion of healthy elderly

paper discusses social deprivation at the national level, encompassing both urban and rural areas. In general, urban areas exhibit better social development than rural regions. However, in the 2010 study, the research was limited to rural areas only.

Social deprivation in China features significant spatial heterogeneity. Regions with higher degrees of social deprivation are primarily concentrated in the west and northeast, whereas those with lower degrees are mainly located in the central regions and coastal areas in the east. This is consistent with the results available [55]. There could be several reasons behind this phenomenon.

First, the spatiotemporal variations in social deprivation may be closely related to regional resource allocation. The measurement of social deprivation encompasses multiple dimensions, including education, income, population, and housing, which vary significantly among different provinces. Furthermore, the developmental resources available in each region also display prominent imbalances. During the initial stages of China's reform, due to accelerated opening up of coastal areas, these regions developed faster, leading to a significant flow of human, physical, and financial resources towards the eastern coastline areas. This resulted in considerable economic development imbalance between eastern and western regions [56]. Subsequently, the Chinese government made strenuous efforts to narrow the economic development gap between the central and eastern regions. For instance, over the past decade, the Chinese government implementing targeted poverty alleviation strategies, transferred a massive amount of talent, funds, and technical resources to 22 provinces in central and western China, while simultaneously accelerating the construction of infrastructures such as transportation and water conservancy [57].

It is noteworthy that although Xinjiang and Ningxia are located in the western region, these two provinces have lower levels of social deprivation, which could be attributed to the implementation of China's "one belt, one road" policy and targeted poverty alleviation policies. These policies aim to promote the development of the western region in China and narrow the economic gap

Table 7 OLS and Spatial regression analysis results

Y	X	OLS				SEM					SLM				
		Coeff	**P**	**R^2**	**AIC**	**Coeff**	**P**	**R^2**	**log-likelihood**	**AIC**	**Coeff**	**P**	**R^2**	**log-likelihood**	**AIC**
IID-A&B	$SD_{Entropy}$	230.043	0.021	0.169	357.061	125.237	0.072	0.552	-169.804	343.608	**143.611**[a]	0.034	0.564	-169.192	344.384
	SD_{CV}	261.396	0.016	0.184	356.509	141.579	0.069	0.551	-169.787	343.574	**157.913**	0.034	0.562	-169.185	344.369
	SD_{CRITIC}	**252.597**	0.084	0.099	359.574	158.957	0.210	0.532	-170.572	345.145	123.042	0.225	0.525	-170.611	347.221
	SD_{PCA}	7.146	0.003	0.260	353.457	4.016	0.031	0.558	-171.182	346.364	**4.236**	0.013	0.573	-168.049	342.98
MRID-A&B	$SD_{Entropy}$	-1.701	0.532	0.014	136.31	**-4.314**	0.064	0.282	-62.664	129.328	-2.899	0.209	0.233	-63.376	132.752
	SD_{CV}	-1.194	0.688	0.006	136.559	**-4.473**	0.087	0.272	-62.900	129.8	-2.654	0.295	0.221	-63.603	133.206
	SD_{CRITIC}	1.115	0.776	0.003	136.646	-3.191	0.439	0.210	-63.870	131.739	-0.646	0.850	0.185	-64.099	134.198
	SD_{PCA}	-0.001	0.983	< 0.001	136.734	-0.091	0.150	0.253	-63.288	130.576	-0.041	0.480	0.204	-63.887	133.774
PR-LWC	$SD_{Entropy}$	1.167	0.214	0.053	69.714	**1.360**	0.090	0.299	-29.552	63.104	1.126	0.150	0.277	-29.893	65.786
	SD_{CV}	1.422	0.164	0.066	69.281	**1.633**	0.066	0.309	-29.322	62.643	1.334	0.117	0.286	-29.701	65.403
	SD_{CRITIC}	1.503	0.266	0.042	70.048	2.153	0.117	0.290	-29.745	63.490	1.402	1.402	0.264	-30.151	66.302
	SD_{PCA}	0.045	0.049	0.127	67.189	**0.052**	0.011	0.369	-27.965	59.930	0.041	0.035	0.327	-28.718	63.435
MMR	$SD_{Entropy}$	51.86	< 0.001	0.856	160.08	50.884	< 0.001	0.857	-77.992	159.986	**48.838**	< 0.001	0.876	-75.853	157.706
	SD_{CV}	56.386	< 0.001	0.852	161.014	54.907	< 0.001	0.855	-78.288	160.576	**53.361**	< 0.001	0.867	-76.958	159.915
	SD_{CRITIC}	**60.285**	< 0.001	0.562	194.605	63.263	< 0.001	0.625	-93.705	191.41	55.301	< 0.001	0.584	-94.635	195.27
	SD_{PCA}	**1.281**	< 0.001	0.833	164.643	1.253	< 0.001	0.846	-79.573	163.147	1.224	< 0.001	0.842	-79.58	165.16
ALE	$SD_{Entropy}$	-10.357	< 0.001	0.476	118.486	-8.607	< 0.001	0.514	-56.635	117.27	**-8.540**	< 0.001	0.583	-54.642	115.284
	SD_{CV}	-11.638	< 0.001	0.506	116.667	-10.354	< 0.001	0.524	-56.042	116.085	**-9.657**	< 0.001	0.594	-54.098	114.195
	SD_{CRITIC}	**-13.218**	< 0.001	0.377	123.87	-11.765	0.001	0.432	-59.070	122.139	-10.298	0.001	0.472	-58.124	122.247
	SD_{PCA}	**-0.303**	< 0.001	0.650	106.014	-0.308	< 0.001	0.651	-50.978	105.957	105.957	< 0.001	0.689	-49.563	105.126
PHE	$SD_{Entropy}$	-32.214	< 0.001	0.355	204.321	-18.647	0.008	0.524	-97.022	198.044	**-22.560**	0.001	0.569	-95.170	196.34
	SD_{CV}	-35.938	< 0.001	0.372	203.501	-21.688	0.005	0.531	-96.748	197.496	**-25.245**	0.001	0.574	-94.933	195.866
	SD_{CRITIC}	-47.664	< 0.001	0.378	203.216	-32.902	0.006	0.521	-96.949	197.899	**-31.953**	0.002	0.545	-95.791	197.582
	SD_{PCA}	-0.883	< 0.001	0.425	200.758	-0.608	0.001	0.577	-95.153	194.307	**-0.640**	< 0.001	0.606	-93.645	193.289

[a] The best a model performances

* $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$

SD Assessing values of social deprivation, *SLM* Spatial lag model, *SEM* Spatial error model

IID-A&B Incidence rate of Class A and B infectious diseases, MRID-A&B Mortality rate of Class A and Class B infectious diseases, PR-LWC Prevalence rate of low weight children, MMR Maternal mortality rate, ALE Average life expectancy, PHE Proportion of healthy elderly

Table 8 Relationships between social deprivation and public health in China

Dependent variable Y	Independent variable X	Equation	P
IID-A&B	$SD_{Entropy}$	$Y=143.611X+0.735273W_I+14.9909$	0.034
	SD_{CV}	$Y=157.913X+0.726999W_I+7.41819$	0.034
	SD_{CRITIC}	$Y=252.597X+88.9345$	0.084
	SD_{PCA}	$Y=4.23593X+0.693981W_I+3.51883$	0.013
MRID-A&B	$SD_{Entropy}$	$Y=-4.31485X+0.574496W_e+2.91359$	0.064
	SD_{CV}	$Y=-4.47319X+0.576616W_e+3.11027$	0.087
	SD_{CRITIC}	$Y=1.11545X+1.22301$	0.775
	SD_{PCA}	$Y=-0.00137X+1.73042$	0.983
PR-LWC	$SD_{Entropy}$	$Y=1.36081X+0.56321W_e+0.671846$	0.090
	SD_{CV}	$Y=1.63283X+0.56223W_e+0.54411$	0.066
	SD_{CRITIC}	$Y=1.50276X+0.401099$	0.266
	SD_{PCA}	$Y=0.05165X+0.571046W_e-0.334712$	0.011
MMR	$SD_{Entropy}$	$Y=48.8383X+0.211307W_I-3.76112$	< 0.001
	SD_{CV}	$Y=53.3609X+0.183648W_I-6.48278$	< 0.001
	SD_{CRITIC}	$Y=60.2851X-14.7907$	< 0.001
	SD_{PCA}	$Y=1.28143X-5.9046$	< 0.001
ALE	$SD_{Entropy}$	$Y=-8.53998X+0.476138W_I+43.4089$	< 0.001
	SD_{CV}	$Y=-9.65728X+0.442818W_I+46.6434$	< 0.001
	SD_{CRITIC}	$Y=-13.2183X+84.1668$	< 0.001
	SD_{PCA}	$Y=-0.303009X+82.51982$	< 0.001
PHE	$SD_{Entropy}$	$Y=-22.5596X+0.539678W_I+30.2161$	0.001
	SD_{CV}	$Y=-25.2451X+0.529738W_I+32.3183$	0.001
	SD_{CRITIC}	$Y=-31.9534X+0.496199W_I+40.4913$	0.002
	SD_{PCA}	$Y=-0.63970X+0.511661W_I+34.4293$	< 0.001

P: significance of the coefficient for independent variable X

IID-A&B Incidence rate of Class A and B infectious diseases, MRID-A&B Mortality rate of Class A and Class B infectious diseases, PR-LWC Prevalence rate of low weight children, MMR Maternal mortality rate, ALE Average life expectancy, PHE Proportion of healthy elderly

between the eastern and western regions. For example, in Ningxia, due to the implementation of precise poverty alleviation policies and counterpart assistance policies, Ningxia has identified its development advantages, developed characteristic agricultural products, and thus promoted the economic growth of Ningxia [58].

Second, the spatiotemporal variations in social deprivation may be closely related to economic circumstances. Previous research has confirmed that people in areas of worse economic development have higher levels of deprivation [59]. the relatively low level of economic development in the western region may lead to a higher degree of social deprivation. This low level of economic development is primarily due to the constraints of geographical environment, and shortage of educational resources in the western region. The western region is characterized by traditional agriculture and industry as its industrial pillars. However, the geographical environment in this region is usually harsh, with extensive high mountains, deserts, and lack of water resources [60]. These geographical features may limit agricultural production and increase the difficulty of infrastructure construction and transportation. Additionally, there are many ethnic minority settlements in the western region where cultural and educational levels might affect economic development.

It has been observed that compared to 2010, the level of social deprivation in northeastern China (including Heilongjiang, Jilin, Liaoning) has not significantly decreased but has shown an upward trend. The reason is that in recent years, the rate of economic growth in northeastern China is declining, with its pace of economic development gradually falling behind other regions [61]. In particular, within the former industrial base of Northeast China, industrial restructuring is regarded as a principal factor of economic decline [62]. Thus, it can be speculated that due to the lagging development in the three northeastern provinces in recent years, the pace of social welfare improvement is slower than expected, thereby exacerbating the degree of social deprivation.

Impact of social deprivation on population health status

Social deprivation shows a positive correlation with the incidence rate of Class A and B infectious diseases, prevalence rate of low weight children, maternal mortality rate, and a negative correlation with average life expectancy, proportion of healthy elderly. The impact between social deprivation and metrics like incidence rate of infectious diseases, maternal mortality rate, average life expectancy, and proportion of healthy elderly exhibit a spatial lag effect. The influence of social deprivation on the prevalence rate of low weight children operates through geographical spatial mechanisms and possesses spatial spillover effects. These results need to be understood from the following aspects.

Firstly, the incidence rate of infectious diseases is closely linked to the prevention and control of these diseases. Infectious diseases pose challenges to public health systems with their rapid onset and widespread transmission characteristics, and effective control requires adequate medical resources and infrastructures [63]. However, in regions with high degrees of social deprivation, economic strength is insufficient to provide ample support for prevention and control of infectious diseases. Furthermore, susceptible populations (like the elderly, children, and those with underlying diseases having weak immunity) are more likely to contract infectious diseases. Studies show that regions with lower economic development levels have poorer population health status [64]. Therefore, people living in regions with higher levels of social deprivation are more prone to infectious diseases.

Secondly, the main cause for low weight in children is malnutrition [65]. Deprivation is strongly associated with malnutrition as a health-changing risk [66]. In regions characterized by high levels of social deprivation, where parents have limited income and educational attainment, and are unable to provide optimal living conditions and maternal prenatal healthcare, children are at an increased risk of experiencing low birth weight and malnutrition.

Thirdly, socioeconomic disadvantage is associated with increased risk for severe maternal morbidity and maternal mortality. This is consistent with the results available [67]. Reducing the maternal mortality rate requires higher medical standards and full-cycle care for pregnant and parturient women [68]. High-quality medical resources usually concentrate in large cities and economically developed provinces. Socially deprived areas, particularly those in the western region, often lack sufficient high-quality medical resources. Moreover, due to low population incomes and limited family assets in these areas, investments in prenatal care and childbirth for pregnant women are insufficient, thus leading to a higher risk of maternal death in highly socially deprived areas.

Fourthly, social deprivation has a serious impact on the health of older people. This is consistent with existing research that material and social deprivation is strongly associated with health deterioration in older people [69]. As a result of the uneven allocation of healthcare resources, high-quality healthcare resources are distributed in areas on account of lower levels of deprivation [70]. Elderly people are deprived of access to basic medical services and long-term medical care in poor areas with worse accessibility of medical resources, limited primary healthcare and lower quality of health service.

Lastly, this study also finds that in regions with lower degrees of social deprivation, average life expectancy is higher, which is consistent with previous research results stating that investments in health care, providing social services, and improving housing conditions help extend life expectancy [71]. Healthy lifestyles are strongly associated with increased life expectancy. People in areas with higher levels of deprivation have lower levels of income, higher levels of perceived personal stress under the pressure of life's burdens, and a lack of health awareness that makes them more likely to adopt unhealthy behaviors, including smoking and high-risk drinking [72]. This is detrimental to the increase in average life expectancy.

Mechanisms on spatial effects of social deprivation on population health status

This study of important discovery is that social deprivation has spatial spillover effects on population health. The impact between social deprivation and population health status like incidence rate of infectious diseases, maternal mortality rate, average life expectancy, and proportion of healthy elderly exhibit a spatial lag effect.

There are two mechanisms that may be able to explain this result. On the one hand, Coordinated Regional Development inevitably leads to the mobility and aggregation of medical resources within the region [73]. While economic level can enhance local population health status, it also has a "siphon effect" on the neighborhood [74]. This phenomenon has caused the concentration of high-quality healthcare resources in areas with lower levels of social deprivation, which has resulted in significant inequalities in the quality of public health services and healthcare services in areas with different levels of deprivation, and thus in health inequalities.

On the other hand, population mobility affects the health of people in neighboring areas through the dissemination of medical services and the spread of lifestyle habits. Modern health concept will be brought to neighboring areas with population mobility, prompting local residents to pay more attention to health management and disease prevention, and raising overall health awareness. However, the spread of detrimental habits (e.g., unhealthy diets, smoking) and infectious diseases also have a potentially negative impact on the health of people living in the surrounding areas [75].

Additionally, there's a spatial error effect between social deprivation and the prevalence rate of low weight children. This might suggest that when evaluating the prevalence rate of low weight children, besides considering local socioeconomic factors, attention should be paid to random errors in the spatial direction. This could come from unobserved spatial factors such as environmental conditions, distribution of medical resources, hygiene policies, and socio-economic interactions across regions.

There are implications for health policy from the result that social deprivation has spatial spillover effects on population health. On the one hand, the spatial spillover effects of social deprivation suggest that health problems are often not constrained by administrative boundaries. This requires a shift in health policy towards regional governance. It extends from the traditional "individual—community" level to the "regional—transregional" level. There is a need for health governance to strengthen inter-regional cooperation, to establish joint monitoring and intervention mechanisms, and to focus on inter-regional interaction effect.

On the other hand, areas of high deprivation are often challenged by resource shortages, and health problems are not limited to the local area, but may also spread to neighboring regions through spatial spillover effects. This underscores the importance of health policies promoting a balanced distribution of health resources across regions in order to avoid the exacerbation of health inequalities due to over-concentration or severe scarcity of resources.

Policy suggestion and limitation

The following recommendations are proposed for the findings of this paper.

Firstly, the government should play an active leading role in providing targeted funding for health care in the western provinces, improving the facilities and equipment of township health centers and village clinics in impoverished areas, prioritizing the provision of public health services such as disease prevention and control, and conducting regular health education activities to improve people's health literacy.

Secondly, it is essential to establish mechanisms for regional cooperation and development, and to encourage economically advanced regions to support and drive social development in disadvantaged areas by financial support and technical assistance. The government should actively promote telemedicine services and mobile medical care and establish a comprehensive telemedicine service network to provide remote consultation services for the grassroots.

Thirdly, incentive policies and financial subsidies should be put into action to encourage the movement of healthcare professionals to primary care and poverty areas. The western provinces should strengthen construction of the rural grassroots health talent team focusing on general practitioners and establish clinical training bases and grass-roots practice bases.

Nevertheless, this study has several limitations. Firstly, due to the effects of selected indicators and data availability, there might be bias in the comprehensive evaluation of social deprivation status conducted in this study. If conditions permit, future selection or adjustment of social deprivation indicators can be done based on data availability. Secondly, given that only one year's data was used to explore the relationship between social deprivation and population health, it is still unclear whether this connection would change over time. Lastly, the study does not compare the relative impacts of different components in the social deprivation indicator system on health outcomes.

Conclusion

This study uses the latest data from China's seventh population census to explore in-depth the social deprivation index, its spatial distribution pattern, and its relationship with health in China. The results show that regions with higher degrees of social deprivation are primarily concentrated in the west and northeast of China, while those with lower degrees are mainly in the central and eastern coastal areas. Social deprivation has a positive correlation with the incidence rate of Class A and B infectious diseases, prevalence rate of low weight children, maternal mortality rate, and a negative correlation with mortality rate of Class A and B infectious disease, average life expectancy, proportion of healthy elderly.

This research enriches the understanding of the relationship between social deprivation and population health in theoretical aspects. Firstly, the study is more comprehensive, selecting a variety of population health variables to explore the relationship between social deprivation and population health. Secondly, by introducing the spatial lag model and spatial error model, this study not only enhances its ability to recognize the spatial dependence of health outcome variables but also provides theoretical support for formulating more precise public health policies. Finally, in the selection of data and methods, this study uses the latest population census data in China and compares four objectively strong methods for measuring social deprivation, ensuring scientific and objective research.

In practical terms, this study reveals the impacts of social deprivation on different population health aspects and social deprivation has spatial spillover effects on population health, further improving the precision of population health policy formulation, advocating for national attention to the impact of unequal regional development on health inequalities, providing reference for the promotion of health equity and the achievement of population-wide health.

Authors' contributions

YZ and YD conceived the idea and design of this study, dealt with data analysis and wrote the manuscript. SQ review and editing the manuscript. All authors read and approved the final manuscript.

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Data availability

The datasets generated and/or analysed during the current study are public and available in the National Bureau of Statistics of China [https://www.stats.gov.cn/sj/pcsj/rkpc/7rp/indexch.htm], and National Health Commission of China [http://www.nhc.gov.cn/mohwsbwstjxxzx/tjtjnj/202305/304a301bfdb444afbf94b1a6c7f83bca.shtml].

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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