Original Article

Hypertension Prevalence, Awareness, Treatment, and Control and Their Associated Socioeconomic Factors in China: A Spatial Analysis of A National Representative Survey*

WANG Wei[1], ZHANG Mei[1], XU Cheng Dong[2], YE Peng Peng[1], LIU Yun Ning[1], HUANG Zheng Jing[1], HU Cai Hong[1], ZHANG Xiao[1], ZHAO Zhen Ping[1], LI Chun[1], CHEN Xiao Rong[1], WANG Li Min[1,#], and ZHOU Mai Geng[1,#]

1. National Center for Chronic and Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, Beijing 100050, China; 2. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Science, Beijing 100101, China

Abstract

Objective We aimed to investigate and interpret the associations between socioeconomic factors and the prevalence, awareness, treatment, and control of hypertension at the provincial level in China.

Methods A nationally and provincially representative sample of 179,059 adults from the China Chronic Disease and Nutrition Surveillance study in 2015–2016 was used to estimate hypertension burden. The spatial Durbin error model was fitted to investigate socioeconomic factors associated with hypertension indicators.

Results Overall, it was estimated that 29.20% of the participants were hypertensive nationwide, among whom, 34.32% were aware of their condition, 27.69% had received antihypertensive treatment, and 7.81% had controlled their condition. Per capita gross domestic product (GDP) was associated with hypertension prevalence (coefficient: −2.95, 95% *CI*: −5.46, −0.45) and control (coefficient: 6.35, 95% *CI*: 1.36, 11.34) among adjacent provinces and was also associated with awareness (coefficient: 2.93, 95% *CI*: 1.12, 4.74) and treatment (coefficient: 2.67, 95% *CI*: 1.21, 4.14) in local province. Beds of internal medicine (coefficient: 2.66, 95% *CI*: 1.08, 4.23) was associated with control in local province. Old dependency ratio (coefficient: −3.58, 95% *CI*: −5.35, −1.81) was associated with treatment among adjacent provinces and with control (coefficient: −1.69, 95% *CI*: −2.42, −0.96) in local province.

Conclusion Hypertension indicators were not only directly influenced by socioeconomic factors of local area but also indirectly affected by characteristics of geographical neighbors. Population-level strategies should involve optimizing supportive socioeconomic environment by integrating clinical care and public health services to decrease hypertension burden.

Key words: Hypertension; China; Cross-sectional study; Socioeconomic factors; Spatial regression; Population-level strategy

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#Correspondence should be addressed to WANG Li Min, Tel: 86-10-83136482, E-mail: wanglimin@ncncd.chinacdc.cn; ZHOU Mai Geng, Tel: 86-10-63041471, E-mail: zhoumaigeng@ncncd.chinacdc.cn

Biographical note of the first author: WANG Wei, female, born in 1991, PhD Candidate, majoring in chronic disease epidemiology and health statistics methodology.

INTRODUCTION

Hypertension is the leading cause of mortality and morbidity worldwide, and it is also a prevalent and modifiable risk factor of cardiovascular diseases (CVDs)[1,2]. Therefore, information on the status of hypertension prevalence, awareness, treatment, and control and their associated factors at the individual level in China, either nationwide[3-7] or even in selected regions[8-10], has been substantially reported to provide effective evidence for informing hypertension prevention and control strategies and mainly to promote healthy lifestyles such as avoidance of obesity, moderate alcohol intake, and no tobacco or drug use[11].

Nevertheless, intersectionality of socioeconomic characteristics of a specific area puts individuals who reside in a certain geographic space at a greater risk of developing hypertension, as accessibility to socioeconomic resources are not always available to reach all individuals[12]. Disparities in hypertension development, diagnosis, and management have persisted in the modern era for years, and socioeconomic factors have increasingly been regarded as the main drivers of efforts to eliminate these disparities[13]. Internationally, previous cross-sectional studies have provided clues of association between socioeconomic factors and hypertension, and some of the cohort studies have also indicated that a greater burden of social determinants would increase the risk of hypertension progression and occurrence of CVD events[13-17]. Yet, with geographically heterogeneous distribution of social development in China, studies on socioeconomic factors associated with hypertension have been rarely documented, and even the few studies that exist are limited in terms of the included indicators and study population or have failed to incorporate a spatial perspective to investigate the relationship between contextual characteristics and hypertension; thus, there are inadequate strategies to decrease hypertension burden at the population level in China[12,14,18]. As a supplement to determine individual level factors for supporting high-risk strategy, understanding the aforementioned issue is particularly relevant to inform population-level strategy during an individual's life course, to initiate large-scale social campaigns, and to optimize allocation of healthcare resources[11,19].

Here, we present findings from the China Chronic Disease and Nutrition Surveillance (CCDNS) study in 2015–2016 involving Chinese adults aged 18 years and above, with the following aims: (i) to describe the distribution of blood pressure (BP) and report the prevalence, awareness, treatment, and control of hypertension among the study participants; (ii) to explore whether and to what extent socioeconomic factors influence hypertension indicators at the ecological level from a spatial perspective; and (iii) to examine and interpret whether the spatial spillover effect and social relativity process could be used to guide the modeling of geographic variation in hypertension indicators and socioeconomic factors by moving beyond the typical theoretical conceptualization of the context in which a province's indicators are associated only with its own features.

METHODS

Study Population

The current study analyzed data from CCDNS conducted in 2015–2016, which was designed and organized by the National Center for Chronic and Noncommunicable Disease Control and Prevention in the Chinese Center for Disease Control and Prevention (China CDC) and supervised by trained local CDC staff. Based on 298 surveillance points across 31 provincial-level administrative divisionsfrom Disease Surveillance Points system in China, CCDNS 2015–2016 aimed to obtain both nationally and provincially representative estimations for the prevalence of main chronic diseases and relevant behavioral and metabolic risk factors through the multistage stratified cluster randomized sampling method by face-to-face questionnaire interviews, physical measurements, and laboratory tests. The sampling process, training procedures, and quality control measures of CCDNS 2015–2016 have been described previously[5,20]. Local CDC invited eligible residents aged 18 years and above from selected households to participate in the survey. In total, 82,995 of the 87,086 households completed the survey, yielding a 95.30% family response rate. Of 194,838 eligible residents, 189,754 completed the survey with a 97.39% individual response rate. The ethics committee of China CDC approved the survey (No. 201519-A), and written informed consent was obtained from each participant. The protocol of the survey complied with the ethical guidelines of the Declaration of Helsinki 1975[5].

BP Measurement and Definition

BP was measured in a seated position by trained field workers in a room at constant temperature of around 25 °C by using an electronic sphygmomanometer (HEM-1300; OMRON Healthcare Product Development Dalian Co., Ltd., Dalian, China) with a wide range cuff (9–17 in.). The BP of each participant was measured three times at 1-min interval after a 5-min rest, and the average of the last two readings was used for analysis. Hypertension was defined in an individual who had a mean systolic blood pressure (SBP) ≥ 140 mmHg or a mean diastolic blood pressure (DBP) ≥ 90 mmHg, or based on a self-reported diagnosis of hypertension in a hospital at the township (community) level or above and had been taking antihypertensive medicines in the past 2 weeks[5,21,22]. Based on the measured BP, the participants were further classified into six categories: optimal (SBP < 120 mmHg and DBP < 80 mmHg); normal (SBP 120–129 mmHg and/or DBP 80–84 mmHg); high-normal (SBP 130–139 mmHg and/or DBP 85–89 mmHg); Stage 1 hypertension (SBP 140–159 mmHg and/or DBP 90–99 mmHg); Stage 2 hypertension (SBP 160–179 mmHg and/or DBP 100–109 mmHg); and Stage 3 hypertension (SBP > 180 mmHg and/or DBP > 110 mmHg)[23]. Awareness of hypertension was defined as those hypertensive patients who self-reported or had been previously diagnosed to have hypertension by health professionals. Treatment of hypertension was limited to those individuals with SBP ≥ 140 mmHg or DBP ≥ 90 mmHg and also to those who self-reported taking a prescribed antihypertensive medicine in the past 2 weeks. Control of hypertension was defined as having measured SBP < 140 mmHg and DBP < 90 mmHg among hypertensive patients who received antihypertensive treatment[5,21,22].

Personal Characteristics and Definition

The characteristics of the study participants included sex, age, couple status, education attainment, employment, annual household income, body weight, smoking status, drinking status, and physical inactivity status. For details, annual household income was classified into 4 quartiles: Q1 (< 16,000 yuan), Q2 (16,000–29,999 yuan), Q3 (30,000–59,999 yuan), and Q4 (> 60,000 yuan). Body mass index (BMI, kg/m^2) was calculated from the height and weight measurements of each individual, and the participants were categorized into four BMI groups: BMI < 18.5 kg/m^2 (underweight), 18.5 kg/m^2 ≤ BMI < 25.0 kg/m^2 (normal weight), 25.0 kg/m^2 ≤ BMI < 30.0 kg/m^2 (overweight), and BMI ≥ 30.0 kg/m^2 (obesity)[24]. Smoking status was categorized into 3 groups: never, former, and current smoker. Excessive drinking was defined as an average daily pure alcohol intake of ≥ 25 g for men and 15 g for women. Physical inactivity was defined as the length of moderate or vigorous physical activity of < 150 min per week[5,21,25].

Socioeconomic Variables Selection and Definition

On the basis of previous literature, we searched PubMed, MEDLINE, and China National Knowledge Infrastructure to identify relevant studies on different variables that might be related to hypertension prevalence, awareness, treatment, and control, including (i) economic development: per capita gross regional product (10,000 yuan per person; GDP, which reflects to each resident's economic contribution or value creation of his country or region, and equals to the ratio of the absolute value of GDP to the average population in that year), average years of education attainment; (ii) city construction: per capita public green areas (m^2 per person); (iii) healthcare resources: number of medical technical personnel in healthcare institutions per 10,000 persons, beds of internal medicine per 10,000 persons; and (iv) social security: old dependency ratio (%). We extracted these covariates from the National Bureau of Statistics. Moreover, by considering the potential cumulative effects of certain socioeconomic variables on hypertension indicators, we used a 5-year lagged value of six socioeconomic variables with the restriction of data availability which belonged to four separate domains at the provincial level in 2010[26,27,28].

Statistical Analysis

This study excluded 10,695 participants with missing SBP/DBP and/or other main information of interests, thereby leaving 179,059 participants available for formal analysis. Given a complex design of analysis, sampling weights were applied to all statistical descriptions and inferences to obtain nationally and provincially representative estimates. Chinese population estimates in 2010 from the National Bureau of Statistics were used for poststratification adjustment[5]. Weighted means or proportions were used to present characteristics of the participants. Weighted means and its 95% confidence interval (95% *CI*) of BP level and its subcategories, as well as weighted prevalence, awareness, treatment, and control of hypertension were estimated for all subgroups. A linear regression model was fitted to examine the differences and trends of BP level among both nominal and ordered categories[25]. The Rao-Scott chi-square test was used to analyze group differences of prevalence among nominal categories, and a logistic regression model was used to examine the trends for ordered categorical variables[25].

Spatial analysis facilitates the investigation of geographic patterns in spatial data and enables to establish a relationship between health-related outcomes and other socioenvironmental factors[29,30]. The prevalence, awareness, treatment, and control of hypertension at the subnational level were spatial data with both geographic attributes and disease distribution values. Grounded in Tobler's First Law, spatial autocorrelation (spatial dependency) refers to the regular but not random distribution of spatial unit attributes within the study scope[31]. It is an essential feature of spatial data based on adjacent geographical distance which enables to make correlations in attribute values of spatial neighbors, and these correlations could cause violation of assumptions of independent samples in conventional (non-spatial) statistical methods[32]. Thus, the estimates of conventional methods are inefficient and biased, which might lead to exclusion of spatial interaction relationship during inference estimation and extrapolation. Therefore, by considering spatial autocorrelation of either dependent variables, independent variables, or error terms in different provinces (spatial units) and by adding certain spatial random terms, we imposed the use of spatial cross-sectional regression models to investigate the association between socioeconomic variables and hypertension indicators, including the spatial lag model, spatial error model, spatial Durbin model, and spatial Durbin error model (ordinary linear square regression was also fitted as a reference estimation for study analysis. Model fit performance was examined by the Akaike Information Criterion, Wald test, Lagrange Multiplier test, Robust Lagrange Multiplier test, and Likelihood Ratio test[33-37]. According to model performance and professional knowledge, SDEM, which incorporates independent variables spatially through both exogenous interactions and error term interactions, was used in the main analysis to investigate the association between socioeconomic factors and hypertension indicators[38]. We then introduced theories of spatial spillover effect and social relative process to speculate and demonstrate how socioeconomic factors influence hypertension indicators from either a focused unit or neighboring provinces. In brief, spatial spillover effect is drawn from both regional development and economics literature, and in this study, it refers to the equidirectional change between socioeconomic characteristics and hypertension indicators in the target unit and its neighbors[39-41]. Social relativity process suggests that the comparison between evaluators and others would induce discrepancy, which might lead to a certain change to reduce the discrepancy by inferior others. As for its introduction in our study, social relativity process referred to that the association between socioeconomic factors and hypertension indicators in a unit would impose the opposite effect on hypertension indicators of geographically proximate units[12,42]. Details of spatial cross-sectional regression modeling procedures, model fit evaluation, and model selection are described in Supplementary Materials: Expanded Methods, available in www.besjournal.com.

In this study, a *P* value of < 0.05 was considered to be statistically significant, and all tests were two-sided. All analyses were performed in SAS version 9.4 (SAS Institute Inc., Cary, NC, USA) by using PROC SURVEYMEANS, PROC SURVEYFREQ, PROC SURVEYREG, and PROC SURVEYLOGISTIC procedures and R version 4.0.4 (The R foundation for Statistical Computing, Lucent Technologies, Auckland, New Zealand) with "spdep" and "spatialreg" packages.

Patients and Public Involvement

There was no patient involvement in this study.

RESULTS

Among the 179,059 participants aged 18 years and above in CCDNS 2015–2016, 46.63% were men and 53.37% were women, 40.85% resided in urban areas and 59.15% in rural areas, and 46.35% were located in north and 53.65% in south (Table 1). For all participants, the population weighted mean of SBP and DBP was 129.01 (95% *CI*: 128.28, 129.74) mmHg and 77.57 (95% *CI*: 77.27, 77.86) mmHg, respectively, and the distribution of study participants in optimal, normal, high normal, stage 1, stage 2, and stage 3 hypertension was as follows: 32.67% (95% *CI*: 31.05, 34.30), 34.20% (95% *CI*: 33.62, 34.77), 17.23% (95% *CI*: 16.54, 17.92), 12.39% (95% *CI*: 11.67, 13.11), 2.93% (95% *CI*: 2.73, 3.13), and 0.58% (95% *CI*: 0.52, 0.65), respectively. Participants who resided in northern areas of China,

Table 1. Characteristics of study participants included in the analysis, CCDNS 2015–2016

Characteristics	Total (*N*, %)	Sex (*n*, %)		Region (*n*, %)		Location (*n*, %)	
		Men	Women	Urban	Rural	Northern	Southern
Total	179,059 (100.00)	83,489 (46.63)	95,570 (53.37)	73,141 (40.85)	105,918 (59.15)	82,989 (46.35)	96,070 (53.65)
Age (years)							
18–29	15,529 (8.67)	6,905 (8.27)	8,624 (9.02)	6,513 (8.90)	9,016 (8.51)	7,548 (9.10)	7,981 (8.31)
30–39	21,442 (11.97)	9,548 (11.44)	11,894 (12.45)	9,307 (12.72)	12,135 (11.46)	10,130 (12.21)	11,312 (11.77)
40–49	39,656 (22.15)	17,784 (21.30)	21,872 (22.89)	15,076 (20.61)	24,580 (23.21)	19,399 (23.38)	20,257 (21.09)
50–59	43,828 (24.48)	20,155 (24.14)	23,673 (24.77)	17,589 (24.05)	26,239 (24.77)	21,343 (25.72)	22,485 (23.40)
60–69	39,815 (22.24)	19,338 (23.16)	20,477 (21.43)	16,575 (22.66)	23,240 (21.94)	17,599 (21.21)	22,216 (23.12)
70–	18,789 (10.49)	9,759 (11.69)	9,030 (9.45)	8,081 (11.05)	10,708 (10.11)	6,970 (8.40)	11,819 (12.30)
Couple status							
Living with another person	162,896 (90.97)	76,207 (91.28)	86,689 (90.71)	65,822 (89.99)	97,074 (91.65)	75,915 (91.48)	86,981 (90.54)
Living alone	16,163 (9.03)	7,282 (8.72)	8,881 (9.29)	7,319 (10.01)	8,844 (8.35)	7,074 (8.52)	9,089 (9.46)
Education							
Illiterate	26,521 (14.81)	5,900 (7.07)	20,621 (21.58)	6,672 (9.12)	19,849 (18.74)	9,860 (11.88)	16,661 (17.34)
Primary school	61,033 (34.09)	28,661 (34.33)	32,372 (33.87)	17,549 (23.99)	43,484 (41.05)	24,848 (29.94)	36,185 (37.67)
Junior high school	54,946 (30.69)	29,762 (35.65)	25,184 (26.35)	23,188 (31.70)	31,758 (29.98)	29,245 (35.24)	25,701 (26.75)
Senior high school	23,159 (12.93)	12,679 (15.19)	10,480 (10.97)	14,440 (19.74)	8,719 (8.23)	12,083 (14.56)	11,076 (11.53)
College graduate or above	13,400 (7.48)	6,487 (7.77)	6,913 (7.23)	11,292 (15.44)	2,108 (1.99)	6,953 (8.38)	6,447 (6.71)
Employment							
Peasant	80,948 (45.21)	40,073 (48.00)	40,875 (42.77)	15,154 (20.72)	65,794 (62.12)	40,345 (48.61)	40,603 (42.26)
Employed	48,410 (27.04)	27,467 (32.90)	20,943 (21.91)	29,249 (39.99)	19,161 (18.09)	20,407 (24.59)	28,003 (29.15)
Housewife/husband	24,762 (13.83)	4,500 (5.39)	20,262 (21.20)	8,942 (12.23)	15,820 (14.94)	10,339 (12.46)	14,423 (15.01)
Unemployed/student	8,461 (4.73)	3,887 (4.66)	4,574 (4.79)	4,898 (6.70)	3,563 (3.36)	3,884 (4.68)	4,577 (4.76)
Retired	16,478 (9.20)	7,562 (9.06)	8,916 (9.33)	14,898 (20.37)	1,580 (1.49)	8,014 (9.66)	8,464 (8.81)

Continued

Characteristics	Total (*N*, %)	Sex (*n*, %)		Region (*n*, %)		Location (*n*, %)	
		Men	Women	Urban	Rural	Northern	Southern
Annual household income							
Q1 (< 16,000 yuan)	36,946 (20.63)	17,968 (21.52)	18,978 (19.86)	7,733 (10.57)	29,213 (27.58)	18,577 (22.38)	18,369 (19.12)
Q2 (16,000–29,999 yuan)	25,795 (14.41)	12,009 (14.38)	13,786 (14.43)	8,251 (11.28)	17,544 (16.56)	13,199 (15.90)	12,596 (13.11)
Q3 (30,000–59,999 yuan)	46,786 (26.13)	21,759 (26.06)	25,027 (26.19)	20,376 (27.86)	26,410 (24.93)	23,914 (28.82)	22,872 (23.81)
Q4 (> 60,000 yuan)	39,257 (21.92)	17,988 (21.55)	21,269 (22.25)	25,774 (35.24)	13,483 (12.73)	16,267 (19.60)	22,990 (23.93)
Don't know/not sure/refused	30,275 (16.91)	13,765 (16.49)	16,510 (17.28)	11,007 (15.05)	19,268 (18.19)	11,032 (13.29)	19,243 (20.03)
Body weight status (BMI categories, kg/m^2)							
Underweight, BMI < 18.5	6,679 (3.73)	2,951 (3.53)	3,728 (3.90)	2,151 (2.94)	4,528 (4.28)	1,980 (2.39)	4,699 (4.89)
Normal weight, BMI: 18.5–24.9	103,630 (57.87)	48,756 (58.40)	54,874 (57.42)	39,505 (54.01)	64,125 (60.54)	42,613 (51.35)	61,017 (63.51)
Overweight, BMI: 25–29.9	57,450 (32.08)	27,091 (32.45)	30,359 (31.77)	26,082 (35.66)	31,368 (29.62)	31,099 (37.47)	26,351 (27.43)
Obesity, BMI ≥ 30	11,300 (6.31)	4,691 (5.62)	6,609 (6.92)	5,403 (7.39)	5,897 (5.57)	7,297 (8.79)	4,003 (4.17)
Smoking status							
Never	120,127 (67.09)	28,104 (33.66)	92,023 (96.29)	50,990 (69.71)	69,137 (65.27)	56,014 (67.50)	64,113 (66.74)
Former	12,040 (6.72)	11,275 (13.50)	765 (0.80)	5,006 (6.84)	7,034 (6.64)	5,586 (6.73)	6,454 (6.72)
Current	46,892 (26.19)	44,110 (52.83)	2,782 (2.91)	17,145 (23.44)	29,747 (28.08)	21,389 (25.77)	25,503 (26.55)
Drinking status							
Non-current	113,499 (63.39)	34,340 (41.13)	79,159 (82.83)	45,512 (62.23)	67,987 (64.19)	53,348 (64.28)	60,151 (62.61)
Low to moderate	41,431 (23.14)	29,355 (35.16)	12,076 (12.64)	18,491 (25.28)	22,940 (21.66)	19,648 (23.68)	21,783 (22.67)
Excessive	16,038 (8.96)	14,640 (17.54)	1,398 (1.46)	5,562 (7.60)	10,476 (9.89)	6,844 (8.25)	9,194 (9.57)
Don't know/not sure/refused/missing	8,091 (4.52)	5,154 (6.17)	2,937 (3.07)	3,576 (4.89)	4,515 (4.26)	3,149 (3.79)	4,942 (5.14)
Physical inactivity							
No	146,102 (81.59)	66,419 (79.55)	79,683 (83.38)	59,700 (81.62)	86,402 (81.57)	67,259 (81.05)	78,843 (82.07)
Yes	32,721 (18.27)	16,951 (20.30)	15,770 (16.50)	13,418 (18.35)	19,303 (18.22)	15,520 (18.70)	17,201 (17.90)
Don't know/not sure/refused/missing	236 (0.13)	119 (0.14)	117 (0.12)	23 (0.03)	213 (0.20)	210 (0.25)	26 (0.03)

who were men, and were former smoker and excessive drinker, were overweight/obese and had physical inactivity, lived with another person, and had lower education attainment and lower annual household income showed comparatively elevated BP levels than their counterparts (Supplementary Table S1, available in www.besjournal.com).

Overall, 29.20% (95% *CI*: 27.7, 30.63) of the participants had hypertension, with a higher proportion of men (31.82%, 95% *CI*: 30.12, 33.53) than women (26.57%, 95% *CI*: 25.29, 27.85). Based on the data from the 2010 Census, an estimated 307 million adults aged > 18 years had hypertension, representing an absolute increase of 15 million individuals since the year 2013. Significant differences in hypertension prevalence were also observed among the subgroups, except for physical inactivity. Among these hypertensive participants, 34.32% (95% *CI*: 32.62, 36.03) were aware of their condition, 27.69% (95% *CI*: 26.01, 29.38) received antihypertensive treatment, and 7.81% (95% *CI*: 7.07, 8.55) had controlled their condition. Among the hypertensive participants who were aware of their condition, 80.68% (95% *CI*: 79.23, 82.14) received antihypertensive treatment, and among these participants who received treatment, 28.20% (95% *CI*: 26.50, 29.89) had their condition under control. Notably, hypertension prevalence, awareness, and treatment increased with age, while the opposite trend was noted for controlled status among the treated hypertensive participants (Table 2). Substantial geographical variations were observed in hypertension prevalence, awareness, treatment, and control. Provinces with higher prevalence were clustered in north and northeast China. Hypertension awareness was poorest in southwest China. Hypertension treatment was lowest in Tibet (8.13%, 95% *CI*: 4.47, 11.80) and below average in many other southern provinces, although Liaoning (20.81%, 95% *CI*: 15.59, 26.03) also showed a lower treatment rate. Hypertension control was highest among provinces along the southeastern seaboard and comparatively lower in southwest and some central provinces such as Henan (4.73, 95% *CI*: 2.29, 7.17) and Shaanxi (3.62%, 95% *CI*: 2.05, 5.19).

Summary statistics of selected socioeconomic variables at the subnational level in 2010 according to certain domains is shown in Table 3. Analysis of socioeconomic factors associated with hypertension prevalence, awareness, treatment, and control was performed separately (Table 4, Supplementary Tables S2 and S3 available in www.besjournal.com). For hypertension prevalence, a decrease of 10,000 yuan per person GDP in other provinces was associated with a roughly 3% increase in prevalence (−2.95, 95% *CI*: −5.46, −0.45) in the target province. For hypertension awareness, an increase of 10,000 yuan per person GDP within a province was positively associated with nearly 3% increase in awareness (2.93, 95% *CI*: 1.12, 4.74) in this specific province; moreover, a decrease of one-unit public green areas among the proximate units was associated with nearly 5% increase in awareness (−4.82, 95% *CI*: −7.13, −2.52) in the specific province. For hypertension treatment, as expected, GDP (2.67, 95% *CI*: 1.21, 4.14) was positively related to treatment within a province, and a decrease of one-unit old dependency ratio among adjacent provinces was associated with an increase of 3.58% in treatment (95% *CI*: −5.35, −1.81) in the target province. For hypertension control, beds of internal medicine per 10,000 persons (2.66, 95% *CI*: 1.08, 4.23) in the target province was positively associated with control, while the old dependency ratio (−1.69, 95% *CI*: −2.42, −0.96) was negatively associated with control in the same province. A positive association was observed between GDP (6.35, 95% *CI*: 1.36, 11.34) in adjacent provinces and hypertension control in a specific province, while an opposite relationship was noted between public green areas (−3.75, 95% *CI*: −6.74, −0.76) and hypertension control.

DISCUSSION

By using data from a national representative survey in CCDNS 2015–2016, this study provided a comprehensive estimate of hypertension prevalence, awareness, treatment, and control and their associated socioeconomic factors in Chinese adults in 2015–2016. BP level, hypertension category, and hypertension prevalence, awareness, treatment, and control were observed to be unequally distributed among the subgroups and across the geographical space. Economic development, city construction, healthcare resource, and social security were population-level socioeconomic factors that influenced hypertension development and management nationally.

It was estimated that hypertension prevalence among Chinese adults in 2015–2016 (29.20%) was much higher than that the results from previous survey observed in China Chronic Disease Risk Factors Surveillance 2013–2014 (27.8%)[5] and China Hypertension Survey in 2012–2015 (23.2%)[3], as well

Table 2. Hypertension prevalence, awareness, treatment, and control among study participants, CCDNS 2015–2016

Characteristics	All participants	Hypertensive participants			Treatment among hypertensive participants who were aware of their condition (%, 95% *CI*)	Controlled hypertensive participants who received antihypertensive treatment (%, 95% *CI*)
	Prevalence (%, 95% *CI*)	Awareness (%, 95% *CI*)	Treatment (%, 95% *CI*)	Control (%, 95% *CI*)		
Overall	29.20 (27.78, 30.63)	34.32 (32.62, 36.03)	27.69 (26.01, 29.38)	7.81 (7.07, 8.55)	80.68 (79.23, 82.14)	28.20 (26.50, 29.89)
Location						
Southern	27.02 (24.97, 29.07)	34.91 (32.69, 37.13)	28.16 (25.94, 30.39)	8.96 (7.80, 10.11)	80.68 (78.79, 82.57)	31.80 (29.47, 34.14)
Northern	32.13 (30.55, 33.71)	33.66 (31.03, 36.30)	27.16 (24.61, 29.72)	6.51 (5.64, 7.39)	80.69 (78.44, 82.94)	23.98 (21.86, 26.11)
P for difference	< 0.001	0.476	0.562	0.001	0.992	< 0.001
Gender						
Men	31.82 (30.12, 33.53)	30.32 (28.67, 31.96)	23.58 (22.05, 25.11)	6.78 (6.07, 7.49)	77.77 (76.00, 79.55)	28.75 (26.79, 30.70)
Women	26.57 (25.29, 27.85)	39.15 (37.14, 41.17)	32.65 (30.62, 34.69)	9.05 (8.12, 9.98)	83.40 (81.90, 84.90)	27.72 (25.81, 29.63)
P for difference	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.271
Age (years)						
18–29	7.42 (6.41, 8.44)	5.12 (3.43, 6.81)	2.00 (1.16, 2.84)	1.09 (0.44, 1.73)	39.09 (23.83, 54.35)	54.31 (32.53, 76.09)
30–39	14.84 (13.24, 16.43)	15.57 (13.27, 17.88)	9.40 (7.69, 11.10)	3.53 (2.36, 4.70)	60.33 (53.79, 66.87)	37.58 (29.21, 45.95)
40–49	28.42 (26.96, 29.87)	26.22 (24.23, 28.20)	19.42 (17.83, 21.02)	6.13 (5.15, 7.12)	74.09 (71.54, 76.65)	31.58 (27.58, 35.58)
50–59	44.74 (43.55, 45.93)	37.49 (35.69, 39.29)	30.51 (28.68, 32.34)	9.74 (8.71, 10.77)	81.38 (79.53, 83.23)	31.93 (29.71, 34.15)
60–69	58.55 (57.16, 59.94)	45.19 (43.37, 47.00)	37.97 (36.17, 39.77)	9.98 (8.98, 10.98)	84.02 (82.59, 85.46)	26.29 (24.43, 28.14)
70–	70.37 (69.10, 71.65)	48.88 (46.29, 51.47)	42.10 (39.37, 44.84)	9.66 (8.57, 10.75)	86.13 (84.23, 88.02)	22.94 (20.63, 25.26)
P for trend	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Couple status						
Living with another person	30.65 (29.38, 31.91)	34.34 (32.67, 36.00)	27.54 (25.90, 29.19)	7.93 (7.16, 8.70)	80.22 (78.72, 81.71)	28.79 (27.09, 30.49)
Living alone	21.38 (18.95, 23.80)	34.24 (31.26, 37.21)	28.86 (25.95, 31.78)	6.86 (5.80, 7.93)	84.31 (81.40, 87.22)	23.78 (20.26, 27.30)
P for difference	< 0.001	0.933	0.249	0.048	0.009	0.005
Education attainment						
Illiterate	52.92 (50.25, 55.60)	29.98 (25.98, 33.97)	24.72 (21.44, 28.01)	7.13 (6.01, 8.25)	82.52 (80.03, 85.02)	21.25 (18.67, 23.84)
Primary school	37.23 (35.92, 38.53)	34.48 (31.81, 37.14)	28.61 (26.23, 31.00)	7.30 (6.23, 8.37)	79.68 (77.87, 81.49)	26.12 (23.34, 28.91)
Junior high school	26.41 (25.09, 27.74)	30.97 (28.83, 33.11)	24.49 (22.47, 26.51)	7.03 (6.13, 7.93)	79.09 (76.83, 81.34)	28.70 (26.32, 31.07)
Senior high school	23.08 (20.55, 25.62)	35.06 (33.05, 37.07)	27.94 (25.96, 29.91)	10.27 (8.89, 11.64)	82.99 (80.73, 85.25)	35.89 (32.99, 38.79)
College graduate or above	13.57 (12.20, 14.94)	40.65 (38.02, 43.28)	33.55 (30.79, 36.30)	10.62 (8.43, 12.81)	82.48 (78.70, 86.26)	42.96 (36.85, 49.06)
P for trend	< 0.001	< 0.001	< 0.001	< 0.001	0.922	< 0.001

Continued

Characteristics	All participants	Hypertensive participants			Treatment among hypertensive participants who were aware of their condition (%, 95% *CI*)	Controlled hypertensive participants who received antihypertensive treatment (%, 95% *CI*)
	Prevalence (%, 95% *CI*)	Awareness (%, 95% *CI*)	Treatment (%, 95% *CI*)	Control (%, 95% *CI*)		
Employment						
Peasant	34.81 (33.68, 35.94)	30.71 (28.86, 32.56)	23.41 (21.53, 25.28)	5.26 (4.57, 5.95)	76.22 (73.87, 78.57)	22.49 (20.92, 24.06)
Employed	20.59 (18.85, 22.34)	28.08 (25.96, 30.21)	21.81 (19.97, 23.65)	7.65 (6.52, 8.77)	77.66 (75.09, 80.22)	35.07 (31.62, 38.52)
Housewife/husband	34.64 (32.80, 36.47)	40.89 (37.88, 43.91)	34.88 (31.98, 37.79)	8.39 (7.14, 9.64)	85.30 (82.76, 87.84)	24.06 (20.83, 27.28)
Unemployment/student	19.12 (16.82, 21.42)	36.41 (32.73, 40.08)	30.47 (26.45, 34.48)	8.16 (6.42, 9.91)	83.69 (78.18, 89.20)	26.79 (22.10, 31.47)
Retired	57.60 (55.87, 59.32)	55.92 (52.66, 59.18)	49.94 (46.64, 53.24)	17.56 (15.32, 19.80)	89.31 (87.52, 91.10)	35.17 (32.07, 38.26)
P for difference	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Annual household income						
Q1 (< 16,000 yuan)	37.89 (36.03, 39.75)	35.15 (32.69, 37.60)	27.90 (25.27, 30.53)	6.20 (5.21, 7.18)	79.39 (76.90, 81.88)	22.20 (19.77, 24.64)
Q2 (16,000–29,999 yuan)	32.45 (30.98, 33.93)	32.46 (30.37, 34.55)	26.06 (24.03, 28.10)	6.38 (5.39, 7.36)	80.30 (77.63, 82.98)	24.47 (21.46, 27.48)
Q3 (30,000–59,999 yuan)	28.67 (27.68, 29.65)	33.28 (31.18, 35.38)	26.00 (24.19, 27.82)	7.13 (6.31, 7.95)	78.14 (76.10, 80.18)	27.41 (25.13, 29.70)
Q4 (> 60,000 yuan)	23.81 (21.00, 26.62)	39.00 (36.81, 41.19)	33.00 (30.85, 35.15)	11.74 (10.50, 12.99)	84.61 (82.89, 86.33)	35.59 (33.34, 37.84)
Don't know/not sure/refused	28.61 (26.89, 30.33)	30.23 (28.05, 32.41)	24.29 (22.18, 26.39)	6.67 (5.75, 7.59)	80.33 (77.47, 83.19)	27.47 (24.87, 30.06)
P for trend[a]	< 0.001	0.505	0.599	<0.001	0.012	< 0.001
Body weight status (BMI categories, kg/m^2)						
Underweight, BMI: < 18.5	12.42 (10.42, 14.41)	25.42 (21.52, 29.31)	17.67 (14.82, 20.52)	4.04 (2.69, 5.40)	69.54 (59.93, 79.15)	22.88 (16.08, 29.67)
Normal weight, BMI: 18.5–24.9	22.48 (21.24, 23.73)	30.99 (29.01, 32.98)	24.70 (22.77, 26.64)	7.76 (6.91, 8.62)	79.70 (77.70, 81.69)	31.43 (29.13, 33.73)
Overweight, BMI: 25–29.9	39.83 (38.29, 41.37)	37.20 (35.41, 39.00)	30.40 (28.68, 32.11)	8.38 (7.52, 9.24)	81.70 (79.99, 83.41)	27.57 (25.59, 29.56)
Obesity, BMI ≥ 30	51.87 (49.48, 54.25)	38.50 (35.47, 41.53)	31.38 (28.31, 34.44)	6.58 (5.08, 8.08)	81.50 (78.58, 84.41)	20.98 (16.83, 25.14)
P for trend	< 0.001	< 0.001	< 0.001	0.689	0.075	< 0.001
Smoking status						
Never	27.16 (25.80, 28.52)	35.53 (33.77, 37.30)	29.50 (27.75, 31.24)	8.19 (7.37, 9.01)	83.01 (81.57, 84.44)	27.77 (25.82, 29.73)
Former	46.97 (44.78, 49.16)	45.64 (42.83, 48.46)	37.28 (34.37, 40.19)	10.14 (8.44, 11.84)	81.68 (78.64, 84.72)	27.20 (23.65, 30.75)
Current	30.78 (28.98, 32.58)	28.32 (26.41, 30.22)	20.91 (19.22, 22.61)	6.28 (5.53, 7.03)	73.85 (71.54, 76.17)	30.03 (27.66, 32.40)
P for difference	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.224

Continued

Characteristics	All participants	Hypertensive participants			Treatment among hypertensive participants who were aware of their condition (%, 95% *CI*)	Controlled hypertensive participants who received antihypertensive treatment (%, 95% *CI*)
	Prevalence (%, 95% *CI*)	Awareness (%, 95% *CI*)	Treatment (%, 95% *CI*)	Control (%, 95% *CI*)		
Drinking status						
Non-current	29.57 (28.55, 30.60)	37.42 (35.52, 39.32)	31.49 (29.66, 33.32)	8.70 (7.91, 9.48)	84.15 (82.82, 85.49)	27.62 (25.96, 29.29)
Low to moderate	24.85 (22.32, 27.38)	29.98 (28.13, 31.84)	22.85 (20.96, 24.74)	6.79 (5.86, 7.72)	76.21 (73.27, 79.14)	29.72 (26.83, 32.61)
Excessive	43.93 (41.87, 45.99)	28.44 (26.11, 30.77)	19.81 (17.62, 21.99)	5.17 (4.04, 6.29)	69.64 (66.23, 73.06)	26.10 (21.83, 30.36)
P for trend	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.924
Excessive drinking						
No	28.05 (26.67, 29.43)	35.30 (33.56, 37.03)	29.02 (27.29, 30.75)	8.15 (7.43, 8.88)	82.23 (80.74, 83.71)	28.09 (26.45, 29.74)
Yes	43.93 (41.87, 45.99)	28.44 (26.11, 30.77)	19.81 (17.62, 21.99)	5.17 (4.04, 6.29)	69.64 (66.23, 73.06)	26.10 (21.83, 30.36)
P for difference	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.356
Physical inactivity						
No	29.06 (27.62, 30.49)	34.54 (32.92, 36.16)	27.67 (26.11, 29.23)	7.96 (7.17, 8.74)	80.11 (78.69, 81.53)	28.76 (26.98, 30.53)
Yes	29.75 (27.88, 31.61)	33.57 (30.75, 36.38)	27.81 (25.01, 30.61)	7.26 (6.42, 8.11)	82.86 (80.28, 85.44)	26.12 (23.51, 28.72)
P for difference	0.332	0.391	0.896	0.054	0.026	0.040

Note. [a]Category “Don't know/not sure/refused” was excluded in the trend test. *CI*: confidence interval.

Table 3. Summary statistics of subnational level socioeconomic variables in China, 2010 (5-year lag)

Domain	Variables	Mean	Min	Q1	Median	Q3	Max
Economic development	Per capita gross regional product (10,000 yuan per person) (GDP)	3.34	1.31	2.25	2.71	4.17	7.61
	Average years of education attainment	8.17	4.76	7.72	8.17	8.60	11.01
City construction	Per capita public green areas (m^2 per person)	10.62	5.78	8.77	10.27	11.82	16.18
Healthcare resource	Number of medical technical personnel in healthcare institutions per 10,000 persons	48.55	25.00	36.00	44.00	52.00	136.00
	Beds of internal medicine per 10,000 persons	6.56	3.36	5.03	6.29	7.47	11.77
Social security	Old dependency ratio (%)	11.46	7.20	10.35	11.10	13.20	16.50

Table 4. Socioeconomic factors of hypertension prevalence, awareness, treatment, and control among Chinese adults, CCDNS 2015–2016: estimated from the spatial Durbin error model

Socioeconomic factors	Estimate (95% *CI*)			
	Being hypertensive	Awareness among hypertensive participants	Treatment among hypertensive participants who were aware of their condition	Controlled hypertensive participants who received antihypertensive treatment
Obesity prevalence (%)	−0.27 (−0.90, 0.36)	–	–	−0.15 (−1.00, 0.69)
Current smoker prevalence (%)	0.37 (0.13, 0.60)***	0.24 (−0.17, 0.65)	0.79 (0.47, 1.10)***	0.39 (0.04, 0.74)**
Excessive drinker prevalence (%)	0.22 (−0.16, 0.60)	−0.47 (−1.02, 0.07)*	−0.79 (−1.41, −0.16)**	−0.15 (−0.76, 0.46)
Physical inactivity prevalence (%)	0.64 (0.31, 0.97)***	0.18 (−0.27, 0.64)	0.73 (0.39, 1.07)***	0.71 (0.29, 1.13)***
GDP (10,000 yuan per person)	0.92 (−0.23, 2.06)	2.93 (1.12, 4.74)***	2.67 (1.21, 4.14)***	0.01 (−2.57, 2.60)
Average years of education attainment	0.91 (−1.33, 3.16)	0.86 (−2.03, 3.76)	−2.75 (−6.67, 1.18)	−0.04 (−4.45, 4.37)
Per capita public green areas (m^2 per person)	−0.39 (−0.84, 0.05)*	−0.22 (−0.95, 0.51)	–	0.54 (−0.22, 1.30)
Number of medical technical personnel in healthcare institutions per 10,000 persons	–	–	0.05 (−0.13, 0.22)	0.002 (−0.29, 0.29)
Beds of internal medicine per 10,000 persons	–	–	0.5 (−1.09, 2.10)	2.66 (1.08, 4.23)***
Old dependency ratio (%)	–	–	0.26 (−0.44, 0.96)	−1.69 (−2.42, −0.96)***
W× Obesity prevalence (%)	2.03 (1.11, 2.94)***	–	–	−2.84 (−5.09, −0.60)**
W× Current smoker prevalence (%)	0.60 (−0.01, 1.20)*	−0.04 (−1.09, 1.01)	1.46 (0.40, 2.52)***	1.24 (0.13, 2.35)**
W× Excessive drinker prevalence (%)	0.003 (−0.95, 0.95)	−0.65 (−1.89, 0.60)	0.07 (−1.45, 1.59)	−0.69 (−2.42, 1.03)
W× Physical inactivity prevalence (%)	0.96 (0.34, 1.59)***	1.73 (0.66, 2.79)***	1.63 (0.68, 2.59)***	0.76 (−0.56, 2.09)
W× GDP (10,000 yuan per person)	−2.95 (−5.46, −0.45)**	0.80 (−2.97, 4.56)	2.97 (−0.05, 5.98)*	6.35 (1.36, 11.34)**
W× Average years of education attainment	−0.47 (−5.70, 4.75)	5.34 (−1.07, 11.75)	0.25 (−7.05, 7.55)	−0.40 (−9.19, 8.39)
W× Per capita public green areas (m^2 per person)	0.28 (−1.30, 1.86)	−4.82 (−7.13, −2.52)***		−3.75 (−6.74, −0.76)**
W× Number of medical technical personnel in healthcare institutions per 10,000 persons	–	–	0.03 (−0.32, 0.39)	0.28 (−0.21, 0.78)
W× Beds of internal medicine per 10,000 persons	–	–	−1.61 (−3.63, 0.40)	−0.78 (−3.35, 1.79)
W× Old dependency ratio (%)	–	–	−3.58 (−5.35, −1.81)***	1.72 (−0.18, 3.62)*
Constant	−38.82 (−59.52, −18.12)***	−8.89 (−52.64, 34.85)	19.57 (−3.16, 42.30)*	−27.94 (−84.87, 28.99)
Observations	31	31	31	31
Log Likelihood	−67.99	−85.24	−71.97	−71.04
igma^2	4	14.23	4.24	4.34
Akaike Inf. Crit.	169.98	200.48	181.94	188.08
Wald Test (*df* = 1)	14.41***	0.45	60.88***	34.85***
LR Test (*df* = 1)	5.40**	0.26	13.85***	4.60**
LM Test	0.02*	0.04	0.01**	0.29

Note. $^{*}P$ < 0.1; $^{**}P$ < 0.05; $^{***}P$ < 0.01. SLM: spatial lag model; SEM: spatial error model; SDM: spatial Durbin model; SDEM: spatial Durbin error model; *CI*: confidence interval; LM: Lagrange Multiplier; LR test: Likelihood Ratio test.

as a pooled analysis of 1,479 population-based measurements for worldwide trends in BP in 2015 (24.1% in men and 20.1% in women)[2]. Nevertheless, compared to the results obtained in the China National Nutrition and Health Survey in 2002[6], the rate of awareness, control, and treatment among the hypertensive participants have been largely improved thereafter. In the past few years, several whole-of-government and whole-of-society policies that target to provide population-level strategy have yielded profound benefits for hypertension prevention and management, such as the establishment and implementation of the Basic Public Health Service program[43] and the National Essential Drug List System[44], the development of a protection mechanism for outpatient medications for hypertensive/diabetic patients, and the promotion of healthy lifestyle such as tobacco control[11]. Despite these measures, awareness, treatment, and control of hypertension remained at a poor level compared to that in some developed and developing countries[2,5,45]. Even though mandated by government regulation, BP measurement was not systematically or routinely monitored when patients visit a health clinic[5]. Moreover, the lack of healthcare professionals and essential antihypertensive medication may also attribute to the low hypertension control rate[5]. Therefore, priorities of continuous lifelong services that facilitate hypertension detection, treatment, and management interventions should be substantially given to primary healthcare settings in order to integrate the discontinuous and fragmented services between communities and clinics[19,46,47].

On the basis of the spatial spillover effect and social relativity process from the spatial perspective, the hypertension indicators in the target unit were not only directly influenced by socioeconomic factors within the same area but also indirectly affected by ecological characteristics of its proximate neighbors. The inverse association between GDP of adjacent provinces and the risk of being hypertensive in the target province might be explained by the social relativity process wherein the positive association between economic development and being hypertensive could impose an opposite effect on hypertension in proximate units: the increase in GDP may accelerate the economic development of its neighbors and thus decrease hypertension prevalence in the target province[12]. For hypertension awareness, as expected, regional GDP could increase the odds of awareness in hypertensive individuals, which indicated that higher social economic status could contribute to regular BP surveillance and disease detection. For hypertension treatment, as the old dependency ratio is an indicator of population ageing, the increase in its value would attenuate healthcare resources and thus induce potential utilization competition. Thus, the disparities in the old dependency ratio between different provinces would induce an opposite effect; thus, we speculated that the increased burden of caring for the elderly might constraint healthcare resources for hypertension treatment in a specific province[12]. For hypertension control, a growing number of internal medicine beds increased the possibility of adequate hypertension control, which might be explained by sufficient healthcare resources that would smoothly provide effective delivery of healthcare services. The effect of elevated GDP also spilled over to indirectly influence hypertension control in neighboring provinces. However, the number of medical technical personnel in healthcare institutions was not observed to be associated with the rate of control, which might be due to limited professional knowledge; thus, enhancing the quality of training for both new and current primary healthcare workforce should be a priority rather than simply increasing the number of technical personnel[19]. Similar to economic development indicators, we presumed that the increase in public green areas may indirectly attract hypertensive patients lived in adjacent provinces and left those disease-free population in target province[12]. Generally, our findings demonstrated that economic development, city construction, healthcare resources, and social security were the factors associated with hypertension indicators at the population level, and this finding was consistent with the results of previous ecological studies in related areas[7,14,16,17,22]. Despite this finding, as most studies have revealed that education attainment was an important indicator of hypertension status at the individual level[14,22], we failed to find a statistically significant association between regional average educated years and hypertension indicators; this may indicate that there were disparities in the relationship between education status and hypertension at the individual and population levels, which needs further confirmation. GDP was also not found to be associated with the prevalence and control of hypertension in the local province; this finding was, however, not consistent with previous studies. The reasons for this difference might be attributed to the limited sample size (which was 31 provinces in this cross-sectional study) and the approach of spatial weight matrix construction, and probably, the reliability and validity of covariates itself.

The findings of this study have important implications for both policymaking and future research. As most hypertensive individuals were still unaware of their conditions and the majority of the general Chinese adults were on the stage of pre-hypertension, substantial community-wide benefits could be obtained for individuals who have not yet entered clinical care and have no immediate detectable risk but might be on a trajectory for developing high BP on the basis of existing epidemiological evidence and for those at high risk or with existing conditions[11]. The identification of the spatial spillover effect and social relativity process of socioeconomic factors on hypertension indicators also suggested that improving social conditions may promote not only the health of the local population but also that of the residents nearby[11]. Individual lifestyle modification and habit formation can be addressed at the population level by governments taking appropriate actions to develop proper socioeconomic environments that would support the creation of communities where healthy choices were easily accessible and readily available[48,49]. Such environments will inherently shape the health behaviors for people at all BP levels, with much greater chance of success than stand-alone interventions targeted at individual patients, including improving soft power of urban construction such as creating livable environment and public dissemination; rationalizing allocation of healthcare resource such as redistribution of healthcare professionals and facilities, and improving social security for treatment measures such as broadening health insurance coverage and reimbursement lists[11]. Additionally, in the coming years, an aging population in the country may broaden the gap between increasing work-related demands and workforce suppliers[50–52]. Thus, social security policy modification and implementation in hypertension prevention and management would be highly essential to not only ameliorate hypertension burden locally but also deliver spillover effect, which might be able to accelerate the enactment of related strategies among the adjacent regions[50–52].

To our knowledge, few studies have attempted to use spatial structure to explain the geographical variations in hypertension indicators in China. By considering a spatial perspective in analyzing a national representative survey, this study was a pilot to provide arguments to interpret the reasons of ecological effects from neighboring regions and confirmed the importance of this perspective for hypertension indicators through SDEM[11,12]. Thus, our findings suggested that spatial structure should not merely be treated as white noise in hypertension research. Instead, it could be used to better understand the magnitude of and the mechanism by which neighboring regions contribute to hypertension burden of a particular area[12,32]. Moreover, proxy from different domains were selected separately in order to be consistent with previous findings both theoretically and practically, which might increase the rationality of the interpretation of results[26].

The present study had several limitations. First, because of the cross-sectional nature of the study, ecological fallacies may exist when investigating population level factors; thus, we could neither infer a causal relationship between socioeconomic variables and hypertension indicators nor generalize the findings to the individual level[26,32]. Second, due to the availability of the provincial level data, some variables such as environmental proxy were inevitably excluded, and inadequate acquisition of long-term cumulative lag effects of socioeconomic factors for hypertension indicators may have led to some of the attributions unexplained. Third, the area of each province in the country was much larger than those geographic units commonly defined in other spatial analysis literature, and the limited sample of 31 provinces may attenuate the efficiency of spatial weight matrix construction in demonstrating spatial relationship and thereby impede the generalization of the current study, for example, the possibility of reverse association direction. Fourth, we excluded 10,695 participants from the analysis, and this led to 5.95% of missing values of BP and other variables, which may also undermine the reliability and validity of our interpretation of the results. Lastly, the study hypothesis largely relied on literature findings and modeling procedures, whereas the selected socioeconomic proxy in different domains may spatially interact with each other through mediating and/or moderating effects; thus, the linear-based, fixed effects spatial regressions may insufficiently interpret the association between socioeconomic proxy and hypertension indicators.

Further adequate data and nonlinear modeling methods should be explored to demonstrate the mechanism more precisely with qualified robustness[53]. More efforts are also warranted to investigate the underlying mechanisms through which socioeconomic factors influence hypertension indicators by using the spatial spillover effect and social relativity process[12].

CONCLUSION

In conclusion, hypertension is a major public health challenge in China. Despite its high prevalence, hypertension awareness, treatment, and control in community-dwelling adults remain poor. Empirical findings of the present study indicated that socioeconomic factors were not only associated with hypertension prevalence, awareness, treatment, and control in the target province but also delivered the spatial spillover effect or social relativity process to indirectly influence hypertension indicators among adjacent geographic units; this was especially true for economic development and policy proxies such as GDP and social security. Therefore, population-level strategies should involve optimizing supportive socioeconomic environment by integrating clinical care and public health services, such as improving soft power of urban construction, rationalizing allocation of healthcare resources, and improving social security for treatment measures, especially in countries with a vast territory and with high spatial heterogeneity in local society development[4,11,19].

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AUTHOR'S CONTRIBUTIONS

LW had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the analysis. MGZ and LW are joint corresponding authors and contributed equally to this work. MGZ, LW, and WW conceived the study design and analytical plan. WW performed statistical analysis and prepared the first draft. WW finished the draft based on comments from other authors. WW was responsible for the revision of draft. LW, MGZ, MZ, ZH, XZ, ZZ, and CL acquired the data. MGZ, LW, MZ, CX, PY, YL, CH, and XC provided technical support in data analysis, interpretation of results, and manuscript drafting. All the authors reviewed the manuscript and provided critical inputs for its revision.

COMPETING INTERESTS

None declared.

DATA AVAILABILITY STATEMENT

No additional data are available.

PARTICIPANT CONSENT FOR PUBLICATION

Not required.

ETHICAL APPROVAL

The study was approved by the Ethics Review Committee of the Chinese Center for Disease Control and Prevention (Approval No.: 201519-A).

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Supplementary Materials: Expanded Methods

Socioeconomic factors associated with hypertension prevalence, awareness, treatment and control in China, 2015–2016: spatial cross-sectional regressions modelling procedures, model fit evaluation and model selection.

Spatial analysis facilitates the investigation of geographic patterns in spatial data and instituting a relationship between health-related outcomes and other socio-environmental factors[28,29]. In this study, spatial cross-sectional regression models were constructed to deal with potential spatial autocorrelation (spatial dependency) of spatial unit attributes (provincial attributes, including hypertension prevalence, awareness, treatment, control, and socioeconomic variables) that violated the assumption of independent samples in conventional (nonspatial) statistical methods, which might lead to inefficient estimation and bias in inference extrapolation[30].

Considering the disparities of socioeconomic variables that influenced hypertension prevalence, awareness, treatment and control, we included different proxy in separate modelling procedures for 4 hypertension accounting for potential cumulative effects of certain indicators accordingly from alternative data selected from National Bureau of Statistics in 2010[11,27]: (i) for hypertension prevalence, metabolic, behavioral, economic development and city construction variables were included; (ii) for hypertension awareness, behavioral, economic development and city construction variables were included; (iii) for hypertension treatment, behavioral, economic development, healthcare resources and social security variables were included; (iv) for hypertension control, metabolic, behavioral, economic development, city construction, healthcare resources and social security variables were all included in the analysis.

Equations of spatial cross-sectional regression models and its different types of spatial effects can be expressed as follows[33,36,37,38,51]:

(i) General spatial cross-sectional regression model: incorporating either dependent endogenous variables, independent variables spatially exogenous interactions, and error term spatially interaction.

$$Y = \rho WY + \alpha I_N + X\beta + WX\vartheta + \mu, \mu = \lambda W\mu + \epsilon \quad (1)$$

In equation (1), Y denotes the dependent variable; W denotes a non-negative spatial weight matrix to explain spatial relationship between spatial units, and presented by an object of $n \times n$ dimensional vector; ρ denotes the (indirect) estimated coefficient that quantify the magnitude of spatially-lagged term WY; α denotes the intercept coefficient; I_N denotes an object of $n \times 1$ dimensional column vector ($i = 1, \ldots, N$); X denotes the exogenous independent variables presented by an object of $n \times k$ dimensional vector ($i = 1, \ldots, N$); β denotes the (direct) estimated coefficient that quantify the magnitude of X towards Y, and presented by an object of $K \times 1$ dimensional column vector; ϑ denotes the (indirect) estimated coefficient that quantify the magnitude of spatially-lagged term WX towards Y, and presented by an object of $K \times 1$ dimensional column vector; λ denotes the estimated coefficients of spatially-lagged stochastic disturbance term $W\mu$, and $\epsilon = (\epsilon_1, \ldots, \epsilon_N)^T$ denotes stochastic disturbance term, among which, ϵ_i is assumed to be an independent identically distributed sample with 0 as mean and σ^2 as variance.

(ii) Spatial lag model (SLM, also called spatial autocorrelation regression, SAR): incorporating dependent variables spatially endogenous interactions.

$$Y = \rho WY + \alpha I_N + X\beta + \epsilon \quad (2)$$

(iii) Spatial error model (SEM): incorporating error term spatially interaction.

$$Y = \alpha I_N + X\beta + \mu, \mu = \lambda W\mu + \epsilon \quad (3)$$

(iv) Spatial Durbin model (SDM): incorporating dependent endogenous variables and independent variables spatially exogenous interactions.

$$Y = \rho WY + \alpha I_N + X\beta + WX\vartheta + \epsilon \quad (4)$$

(v) Spatial Durbin error model (SDEM): incorporating independent variables spatially exogenous interactions and error term spatially interaction.

$$Y = \alpha I_N + X\beta + WX\vartheta + \mu, \mu = \lambda W\mu + \epsilon \quad (5)$$

Spatial cross-sectional regression modelling procedures were as follows[33,34,38,51]:

Step1. Data preparation. Shapiro-Wilk normality test was used to examine the distribution of hypertension indicators. Multicollinearity analysis was used to ensure that the variance inflation factor (VIF) of all independent variables was less than 10.

Step2. Moran's I calculation. Global Moran's I statistics was calculated to detect potential spatial autocorrelation of hypertension indicators.

Step3. OLS estimation. The ordinary least square (OLS) regression model was established to select independent variables with the goal of maximum adjusted R^2, and to ensure that the final model could pass F-test while the selected independent variables could pass *t*-test. After that, the Lagrange Multiplier test (LM) and Robust Lagrange Multiplier test (Robust LM) were used to determine whether the effects of spatial lag or spatial error terms existed in the model.

Step4. Evaluation of spatial regression models. If the LM test passed, the SLM or SEM will be used to quantify the spatial effects of associated factors. Then SDM was introduced to further describe the direct effect, indirect effect, and total effect of the socioeconomic variables on hypertension indicators. The Likelihood Ratio (LR) test was applied to examine whether SDM should be simplified to SAR or SEM.

Step5. Evaluation of different SDM. The best model fitted for hypertension indicators was identified. Theoretically, a smaller Akaike Information Criterion (AIC) indicated a better model performance. Besides, Wald test, LM test, Robust LM test and LR test were approaches to examine the significance of spatial lags, a sequence of Wald test > LR test > LM test of same model indicated the plausibility interpretation of spatial lags configuration in modelling construction for dependent variables, independent variables and error term[33,34,38]. Accordingly, we selected SDEM as main model for analysis as shown in equation (5). We defined Y as hypertension prevalence, awareness, treatment and control and X as socioeconomic variables in each province of the country. We defined W as a first order queen contiguity weight matrix. In this way, β represented the estimated coefficient that quantify the direct magnitude of socioeconomic variables towards hypertension indicators in local province (Y); ϑ represented estimated coefficient that quantify the indirect effects of socioeconomic variables from adjacent provinces (WX) towards hypertension indicators in local province (Y).

Consequently, the prevalence (W = 0.97, P = 0.443), awareness (W = 0.96, P = 0.333), treatment (W = 0.95, P = 0.106) and control (W = 0.97, P = 0.563) of hypertension at provincial level was normally distributed. Multicollinearity was not observed in selected socioeconomic variables (Supplemental Materials: Online Table S3). Significant global autocorrelation was detected for hypertension prevalence (P < 0.001), awareness (P = 0.022), treatment (P = 0.001); although indicator for hypertension control (P = 0.089) was not significantly tested spatial autocorrelated, we regarded it as spatial data in the consideration of its spatial attributes. Subsequently, according to modelling selection criterion, including AIC, Wald test, LM test, Robust LM test and LR test, the construction of SLM in hypertension awareness and treatment estimation was irrational in describing spatial relationship of spatial units, which should be excluded in model selection. Furthermore, although AIC indicated that SDM outperformed SDEM slightly in hypertension awareness, treatment and control estimation, we failed to provide robust theoretical evidence the existence of spatial lags for all 4 hypertension indicators. Additionally, we were mostly interested in controlling for spatial clustering of the specific independent variables and error term rather than the endogenous variables, we therefore avoided global spillover models which subjectively restrict the magnitude of spillover effects like SDM, and meanwhile we did not consider spatial models that used spatially lagged dependent variables (e.g. spatial Durbin, spatial autoregressive model) which may be more difficult to interpret. As a result, we selected SDEM to determine, quantify and interpret the relationship between socioeconomic variables and hypertension indicators in the main analysis[32,35]. Theoretically, SDEM returned estimates for direct, indirect, and total impacts for each explanatory variable. The direct and indirect impacts or (coefficients) for each of the socioeconomic factors and their relationship to hypertension indicators were important for this research. Essentially, the direct impacts represented local effects and the indirect impacts represented neighbor effects. The indirect/neighbor impacts were derived from the relationship of neighboring socioeconomic factors values to local hypertension indicators values. The total impacts estimation did not include a measure of significance and was the sum of the direct and indirect impacts for each coefficient. In this study, we were interested in identifying local and neighborhood level factors rather than assessing the total impacts of a factor on hypertension indicators. Therefore, we decided to not report the total impacts.

Supplementary Table S1. Systolic blood pressure, diastolic blood pressure and classification of hypertension among different groups of study participants in China, CCDNS 2015-16

Characteristics	Blood pressure (mmHg, 95% *CI*)		Classification of hypertension (%, 95% *CI*)					
	SBP	DBP	Optimal	Normal	High normal	Stage 1 hypertension	Stage 2 hypertension	Stage 3 hypertension
Overall	129.01	77.57	32.67	34.2	17.23	12.39	2.93	0.58
	(128.28, 129.74)	(77.27, 77.86)	(31.05, 34.30)	(33.62, 34.77)	(16.54, 17.92)	(11.67, 13.11)	(2.73, 3.13)	(0.52, 0.65)
Location								
Southern	127.56	76.81	35.54	33.79	16.21	11.25	2.68	0.53
	(126.48, 128.64)	(76.39, 77.22)	(33.24, 37.85)	(33.09, 34.49)	(15.21, 17.21)	(10.19, 12.32)	(2.41, 2.94)	(0.44, 0.61)
Northern	130.95	78.59	28.82	34.74	18.6	13.91	3.27	0.66
	(130.23, 131.66)	(78.23, 78.94)	(27.00, 30.64)	(33.78, 35.71)	(17.85, 19.34)	(13.17, 14.65)	(2.99, 3.55)	(0.57, 0.75)
P for difference	< 0.001	< 0.001	< 0.001	0.117	< 0.001	< 0.001	0.002	0.031
Gender								
Men	131.31	79.79	24.01	38.6	19.99	13.74	3.06	0.6
	(130.65, 131.96)	(79.48, 80.10)	(22.68, 25.33)	(37.58, 39.61)	(19.16, 20.82)	(12.83, 14.66)	(2.83, 3.28)	(0.52, 0.69)
Women	126.69	75.33	41.39	29.77	14.45	11.03	2.8	0.56
	(125.85, 127.54)	(75.00, 75.65)	(39.21, 43.56)	(28.75, 30.79)	(13.76, 15.13)	(10.40, 11.66)	(2.58, 3.02)	(0.48, 0.64)
P for difference	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.015	0.469
Age								
18–29	118.5	72.6	53.12	33.35	9.89	3.24	0.36	0.04
	(117.94, 119.05)	(72.27, 72.92)	(51.32, 54.92)	(31.79, 34.91)	(8.73, 11.05)	(2.64, 3.84)	(0.17, 0.54)	(0.00, 0.10)
30–39	122.21	76.47	43.16	36.07	13.2	6.37	0.98	0.21
	(121.32, 123.11)	(75.97, 76.98)	(40.30, 46.03)	(34.57, 37.58)	(11.91, 14.49)	(5.58, 7.16)	(0.73, 1.23)	(0.11, 0.31)
40–49	128.7	79.89	29.06	36.28	19.01	12.55	2.68	0.41
	(128.08, 129.32)	(79.60, 80.19)	(27.59, 30.54)	(35.35, 37.22)	(18.30, 19.72)	(11.52, 13.59)	(2.41, 2.95)	(0.32, 0.50)
50-59	136.31	81.47	17.7	35.11	23.03	18.69	4.52	0.95
	(135.72, 136.90)	(81.18, 81.76)	(16.51, 18.89)	(34.38, 35.85)	(22.18, 23.89)	(17.94, 19.44)	(4.17, 4.88)	(0.80, 1.09)
60–69	142.93	80.36	11.65	31.45	25.74	24.06	5.96	1.14
	(142.26, 143.59)	(80.03, 80.69)	(10.85, 12.46)	(30.73, 32.16)	(25.07, 26.40)	(23.33, 24.79)	(5.50, 6.43)	(0.93, 1.34)
70–	148.99	77.8	7.52	27.22	23.33	29.51	10.03	2.38
	(148.17, 149.80)	(77.46, 78.14)	(6.66, 8.39)	(26.25, 28.19)	(22.22, 24.45)	(28.51, 30.50)	(9.20, 10.86)	(2.07, 2.70)
P for trend	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Continued

Characteristics	Blood pressure (mmHg, 95% *CI*)		Classification of hypertension (%, 95% *CI*)					
	SBP	DBP	Optimal	Normal	High normal	Stage 1 hypertension	Stage 2 hypertension	Stage 3 hypertension
Couple status								
Living with another person	129.65 (129.01, 130.29)	78.12 (77.84, 78.39)	31.23 (29.71, 32.75)	34.27 (33.70, 34.84)	17.8 (17.20, 18.41)	13.09 (12.41, 13.76)	3.02 (2.82, 3.22)	0.59 (0.52, 0.66)
Living alone	125.53 (124.30, 126.77)	74.59 (74.11, 75.06)	40.49 (38.06, 42.91)	33.81 (32.09, 35.54)	14.11 (12.57, 15.66)	8.6 (7.48, 9.73)	2.45 (2.00, 2.90)	0.54 (0.40, 0.68)
P for difference	< 0.001	< 0.001	< 0.001	0.612	< 0.001	< 0.001	0.021	0.516
Education								
Illiterate	141.32 (140.05, 142.60)	78.35 (77.81, 78.89)	16.39 (14.46, 18.32)	30.88 (29.94, 31.81)	22.08 (20.85, 23.30)	22.21 (21.04, 23.39)	6.89 (6.10, 7.67)	1.56 (1.18, 1.93)
Primary school	133.63 (133.04, 134.23)	78.83 (78.54, 79.12)	24.59 (23.22, 25.96)	34.53 (33.69, 35.38)	20 (19.37, 20.63)	16.16 (15.37, 16.95)	3.9 (3.59, 4.22)	0.81 (0.70, 0.92)
Junior high school	127.57 (126.96, 128.18)	77.98 (77.66, 78.31)	33.75 (32.18, 35.33)	35.05 (34.19, 35.92)	16.94 (16.10, 17.78)	11.33 (10.64, 12.02)	2.44 (2.23, 2.65)	0.49 (0.39, 0.58)
Senior high school	125.29 (124.15, 126.44)	76.89 (76.42, 77.35)	38.48 (35.84, 41.13)	34.49 (33.33, 35.66)	15.37 (13.73, 17.01)	9.39 (8.13, 10.66)	1.98 (1.66, 2.29)	0.29 (0.20, 0.37)
College graduate or above	120.66 (119.92, 121.40)	74.66 (74.27, 75.05)	48.01 (45.96, 50.07)	33.38 (32.12, 34.65)	12.08 (10.89, 13.28)	5.44 (4.71, 6.16)	0.94 (0.61, 1.27)	0.14 (0.06, 0.22)
P for trend	< 0.001	< 0.001	< 0.001	0.183	< 0.001	< 0.001	< 0.001	< 0.001
Employment								
Peasant	132.84 (132.34, 133.35)	78.87 (78.53, 79.21)	25.06 (23.76, 26.36)	35.46 (34.66, 36.25)	19.71 (19.11, 20.31)	15.19 (14.63, 15.75)	3.85 (3.57, 4.14)	0.73 (0.63, 0.83)
Employed	124.42 (123.39, 125.44)	76.87 (76.43, 77.30)	39.72 (37.29, 42.16)	34.81 (33.93, 35.70)	14.83 (13.74, 15.93)	8.66 (7.70, 9.63)	1.64 (1.44, 1.85)	0.33 (0.25, 0.41)
Housewife/husband	131.36 (130.43, 132.29)	76.93 (76.48, 77.37)	33.13 (31.40, 34.87)	29.95 (28.68, 31.23)	17.42 (16.43, 18.42)	14.42 (13.50, 15.34)	4.14 (3.59, 4.68)	0.93 (0.72, 1.15)
Unemployment/student	123.85 (122.90, 124.80)	75 (74.50, 75.50)	44.07 (41.34, 46.80)	32.99 (30.55, 35.44)	12.8 (11.27, 14.33)	7.81 (6.65, 8.96)	1.86 (1.33, 2.39)	0.47 (0.22, 0.71)
Retired	139.38 (138.55, 140.20)	78.96 (78.60, 79.32)	14.72 (13.24, 16.19)	31.99 (30.85, 33.14)	24.03 (22.72, 25.35)	23.19 (21.69, 24.70)	5.15 (4.59, 5.71)	0.91 (0.72, 1.10)
P for difference	< 0.001	< 0.001	< 0.001	< 0.001	0.031	0.175	0.958	0.511

Continued

Characteristics	Blood pressure (mmHg, 95% *CI*)		Classification of hypertension (%, 95% *CI*)					
	SBP	DBP	Optimal	Normal	High normal	Stage 1 hypertension	Stage 2 hypertension	Stage 3 hypertension
Annual household income								
Q1 (< 16,000 yuan)	133.89 (133.05, 134.73)	78.38 (77.99, 78.77)	25.71 (23.95, 27.48)	32.9 (32.00, 33.81)	19.6 (18.71, 20.49)	16.51 (15.67, 17.34)	4.29 (3.91, 4.66)	0.99 (0.83, 1.14)
Q2 (16,000–29,999 yuan)	131.07 (130.45, 131.69)	78.43 (78.09, 78.78)	29.04 (27.37, 30.70)	34.39 (33.24, 35.54)	18.21 (17.19, 19.24)	14.28 (13.43, 15.14)	3.32 (2.97, 3.67)	0.76 (0.58, 0.93)
Q3 (30,000–59,999 yuan)	128.95 (128.50, 129.40)	77.88 (77.60, 78.16)	31.68 (30.20, 33.15)	35.06 (34.06, 36.06)	17.61 (16.92, 18.29)	12.23 (11.63, 12.82)	2.93 (2.68, 3.19)	0.5 (0.41, 0.59)
Q4 (> 60,000 yuan)	125.56 (124.24, 126.87)	76.66 (76.14, 77.18)	38.34 (35.38, 41.30)	34.43 (33.36, 35.50)	15.63 (14.05, 17.21)	9.38 (8.08, 10.67)	1.86 (1.56, 2.17)	0.37 (0.28, 0.45)
Don't know/not sure/refused	128.79 (127.90, 129.69)	77.18 (76.76, 77.59)	33.96 (31.82, 36.09)	33.49 (32.28, 34.71)	16.37 (15.33, 17.41)	12.45 (11.50, 13.40)	3.15 (2.79, 3.51)	0.58 (0.47, 0.69)
P for trend[a]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Body weight status (BMI categories, kg/m^3)								
Underweight, BMI < 18.5	117.67 (116.10, 119.24)	71.24 (70.53, 71.95)	61.78 (58.39, 65.17)	23.41 (21.16, 25.66)	7.59 (6.12, 9.06)	5.63 (4.59, 6.68)	1.41 (1.06, 1.75)	0.18 (0.10, 0.26)
Normal weight, BMI: 18.5–24.9	125.89 (125.20, 126.58)	75.53 (75.26, 75.81)	39.39 (37.66, 41.12)	33.8 (33.08, 34.52)	14.64 (13.80, 15.48)	9.58 (8.92, 10.25)	2.14 (1.96, 2.32)	0.44 (0.37, 0.51)
Overweight, BMI: 25–29.9	134.44 (133.88, 135.00)	81 (80.72, 81.27)	19.92 (18.83, 21.00)	36.61 (35.74, 37.47)	22.37 (21.70, 23.03)	16.38 (15.58, 17.18)	3.96 (3.65, 4.27)	0.77 (0.68, 0.87)
Obesity, BMI >=30	139.63 (138.61, 140.64)	84.28 (83.83, 84.73)	11.33 (9.56, 13.09)	34.13 (32.18, 36.09)	23.31 (21.88, 24.74)	23.72 (22.20, 25.24)	6.27 (5.55, 6.99)	1.24 (0.86, 1.63)
P for trend	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Smoking status								
Never	127.7 (126.96, 128.45)	76.52 (76.23, 76.81)	36.53 (34.84, 38.21)	32.68 (31.95, 33.41)	15.97 (15.28, 16.66)	11.52 (10.82, 12.23)	2.75 (2.53, 2.96)	0.55 (0.49, 0.62)
Former	137.05 (136.13, 137.97)	81.25 (80.85, 81.65)	16.33 (14.74, 17.93)	35.36 (33.29, 37.44)	23.82 (22.65, 24.99)	19.09 (17.70, 20.48)	4.62 (3.88, 5.37)	0.77 (0.56, 0.98)
Current	130.65 (129.88, 131.43)	79.43 (79.02, 79.83)	26.35 (24.40, 28.30)	37.71 (36.78, 38.63)	19.05 (18.02, 20.08)	13.22 (12.32, 14.11)	3.05 (2.77, 3.33)	0.62 (0.51, 0.74)
P for trend	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.019	0.299

Continued

Characteristics	Blood pressure (mmHg, 95% *CI*)		Classification of hypertension (%, 95% *CI*)					
	SBP	DBP	Optimal	Normal	High normal	Stage 1 hypertension	Stage 2 hypertension	Stage 3 hypertension
Drinking status								
Non-current	128.92	76.66	34.59	32.88	16.43	12.48	3.01	0.61
	(128.36, 129.47)	(76.40, 76.93)	(33.13, 36.05)	(32.07, 33.70)	(15.89, 16.96)	(11.94, 13.02)	(2.80, 3.21)	(0.54, 0.69)
Low to moderate	127.35	77.85	32.98	36.48	17.27	10.57	2.35	0.36
	(126.13, 128.56)	(77.32, 78.38)	(30.25, 35.71)	(35.42, 37.55)	(15.81, 18.73)	(9.27, 11.86)	(2.03, 2.67)	(0.27, 0.44)
Excessive	136.42	83.19	17.04	34.32	23.67	19.08	4.71	1.19
	(135.57, 137.27)	(82.68, 83.69)	(15.17, 18.91)	(33.00, 35.64)	(22.47, 24.87)	(17.60, 20.56)	(4.04, 5.38)	(0.89, 1.48)
P for difference	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.029	0.104
Excessive drinking								
No	128.41	77.05	34.07	34.04	16.7	11.86	2.79	0.53
	(127.68, 129.14)	(76.75, 77.34)	(32.39, 35.76)	(33.42, 34.67)	(16.03, 17.36)	(11.15, 12.58)	(2.61, 2.98)	(0.47, 0.59)
Yes	136.42	83.19	17.04	34.32	23.67	19.08	4.71	1.19
	(135.57, 137.27)	(82.68, 83.69)	(15.17, 18.91)	(33.00, 35.64)	(22.47, 24.87)	(17.60, 20.56)	(4.04, 5.38)	(0.89, 1.48)
P for difference	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Physical inactivity								
No	128.96	77.6	32.68	34.22	17.34	12.31	2.89	0.57
	(128.26, 129.66)	(77.30, 77.90)	(31.09, 34.27)	(33.61, 34.83)	(16.60, 18.08)	(11.60, 13.02)	(2.69, 3.09)	(0.50, 0.63)
Yes	129.17	77.43	32.69	34.11	16.78	12.69	3.08	0.64
	(128.19, 130.15)	(77.06, 77.81)	(30.45, 34.93)	(32.90, 35.33)	(15.79, 17.77)	(11.66, 13.72)	(2.72, 3.45)	(0.52, 0.76)
P for difference	0.548	0.328	0.987	0.872	0.264	0.31	0.261	0.198

Note. [a]Category "Don't know /not sure/refused" was excluded in the trend test. SBP: systolic blood pressure; DBP: diastolic blood pressure.

Supplementary Table S2. Collinearity diagnostics and variance inflation factor (VIF) of subnational level socioeconomic variables in China, 2010 (5-year lag)

Variables	Being hypertensive	Awareness among hypertensive participants	Treatment among hypertensive participants who were aware of their condition	Controlled hypertensive participants who received antihypertensive treatment
Obesity prevalence (%)	1.67	–	–	–
Current smoker prevalence (%)	1.47	1.38	1.94	1.94
Excessive drinker prevalence (%)	1.43	1.32	1.46	1.46
Physical inactivity prevalence (%)	1.13	1.13	1.66	1.66
GDP (10,000 yuan per person)	4.09	3.89	5.31	5.31
Average years of education attainment	5.44	4.07	8.10	8.10
Per capita public green areas (m^2 per person)	1.09	1.09	1.34	1.34
Number of medical technical personnel in healthcare institutions per 10,000 person	–	–	6.89	6.89
Beds of internal medicine per 10,000 person	–	–	2.59	2.59
Old dependency ratio (%)	–	–	1.63	1.63
OLS collinearity diagnostics (VIF)	2.69	2.65	3.20	1.64

Supplementary Table S3-1. Socioeconomic factors of the odds of being hypertensive among all participants in CCDNS 2015−2016

Socioeconomic variables	Estimate (95% *CI*)				
	OLS	SLM	SEM	SDM	SDEM
Obesity prevalence (%)	0.83 (0.30, 1.36)***	0.71 (0.24, 1.18)***	0.87 (0.48, 1.26)***	0.19 (−0.50, 0.88)	−0.27 (−0.90, 0.36)
Current smoker prevalence (%)	0.38 (0.02, 0.74)*	0.36 (0.06, 0.66)**	0.42 (0.10, 0.73)***	0.36 (0.09, 0.63)***	0.37 (0.13, 0.60)***
Excessive drinker prevalence (%)	0.52 (0.05, 1.00)**	0.42 (0.01, 0.84)**	0.50 (0.12, 0.89)**	0.19 (−0.16, 0.54)	0.22 (−0.16, 0.60)
Physical inactivity prevalence (%)	0.58 (0.21, 0.95)***	0.53 (0.22, 0.84)***	0.64 (0.35, 0.92)***	0.60 (0.28, 0.93)***	0.64 (0.31, 0.97)***
GDP (10,000 yuan per person)	−0.31 (−1.85, 1.22)	−0.09 (−1.38, 1.19)	−0.53 (−1.83, 0.78)	0.54 (−0.66, 1.74)	0.92 (−0.23, 2.06)
Average years of education attainment	1.01 (−1.80, 3.81)	0.46 (−1.92, 2.84)	1.35 (−1.02, 3.72)	0.57 (−1.63, 2.76)	0.91 (−1.33, 3.16)
Per capita public green areas (m^2 per person)	−0.12 (−0.67, 0.43)	−0.25 (−0.71, 0.22)	−0.04 (−0.50, 0.42)	−0.40 (−0.87, 0.07)*	−0.39 (−0.84, 0.05)*
$W\times$Obesity prevalence (%)	–	–	–	1.59 (0.45, 2.73)***	2.03 (1.11, 2.94)***
$W\times$Current smoker prevalence (%)	–	–	–	0.72 (0.03, 1.42)**	0.60 (−0.01, 1.20)*
$W\times$Excessive drinker prevalence (%)	–	–	–	0.23 (−0.66, 1.12)	0.003 (−0.95, 0.95)
$W\times$Physical inactivity prevalence (%)	–	–	–	1.05 (0.34, 1.75)***	0.96 (0.34, 1.59)***
$W\times$GDP (10,000 yuan per person)	–	–	–	−2.62 (−5.20, -0.05)**	−2.95 (−5.46, -0.45)**
$W\times$Average years of education attainment	–	–	–	1.4 (−3.72, 6.52)	−0.47 (−5.70, 4.75)
$W\times$Per capita public green areas (m^2 per person)	–	–	–	0.17 (−1.30, 1.65)	0.28 (−1.30, 1.86)
Constant	−8.79 (−29.22, 11.63)	−9.17 (−26.47, 8.13)	−14.08 (−29.25, 1.09)*	−46.54 (−74.27, −18.81)***	−38.82 (−59.52, −18.12)***

Continued

Socioeconomic variables	Estimate (95% *CI*)				
	OLS	SLM	SEM	SDM	SDEM
Observations	31	31	31	31	31
R^2	0.63				
Adjusted R^2	0.51				
Log Likelihood		−78.54	−79.02	−70.02	−67.99
$sigma^2$		9.11	9.34	5.24	4
Akaike Inf. Crit.	176.78	177.09	178.03	174.03	169.98
Residual Std. Error	3.64 (df = 23)				
F Statistic	5.54^{***} (df = 7; 23)				
Wald Test (df = 1)		2.33	1.76	1.7	14.41^{***}
LR Test (df = 1)		1.7	0.75	1.34	5.40^{**}
LM Test		0.25	0.62	0.01^{**}	0.02^{*}

Note. $^{*}P < 0.1$; $^{**}P < 0.05$; $^{***}P < 0.01$. OLS: ordinary leas square; SLM: spatial lag model; SEM: spatial error model; SDM: spatial Durbin model; SDEM: spatial Durbin error model; *CI*: confidence interval; LM: Lagrange Multiplier; LR: Lagrange multiplier.

Supplementary Table S3-2. Socioeconomic factors of the odds of being aware of hypertension condition among hypertensive participants

Socioeconomic variables	Estimate (95% *CI*)				
	OLS	SLM	SEM	SDM	SDEM
Current smoker prevalence (%)	−0.01 (−0.54, 0.53)	￥−0.02 (−0.47, 0.43)	0.005 (−0.44, 0.45)	0.21 (−0.19, 0.61)	0.24 (−0.17, 0.65)
Excessive drinker prevalence (%)	−0.5 (−1.19, 0.20)	￥−0.43 (−1.03, 0.17)	−0.49 $(−1.01, 0.02)^{*}$	−0.50 $(−1.04, 0.05)^{*}$	−0.47 $(−1.02, 0.07)^{*}$
Physical inactivity prevalence (%)	0.17 (−0.40, 0.74)	0.28 (−0.21, 0.77)	0.35 $(−0.06, 0.75)^{*}$	0.23 (−0.24, 0.69)	0.18 (−0.27, 0.64)
GDP (10,000 yuan per person)	3.42 $(1.14, 5.70)^{***}$	3.71 $(1.76, 5.65)^{***}$	3.89 $(2.09, 5.70)^{***}$	3.13 $(1.32, 4.94)^{***}$	2.93 $(1.12, 4.74)^{***}$
Average years of education attainment	−0.07 (−3.76, 3.63)	0.18 (−3.02, 3.39)	−0.79 (−3.65, 2.06)	0.4 (−2.53, 3.34)	0.86 (−2.03, 3.76)
Per capita public green areas (m^2 per person)	0.47 (−0.37, 1.31)	0.47 (−0.24, 1.19)	0.22 (−0.45, 0.89)	−0.18 (−0.91, 0.56)	−0.22 (−0.95, 0.51)
W×Current smoker prevalence (%)	–	–	–	0.04 (−0.97, 1.04)	−0.04 (−1.09, 1.01)
W×Excessive drinker prevalence (%)	–	–	–	−0.54 (−1.80, 0.72)	−0.65 (−1.89, 0.60)
W×Physical inactivity prevalence (%)	–	–	–	1.58 $(0.54, 2.62)^{***}$	1.73 $(0.66, 2.79)^{***}$
W×GDP (10,000 yuan per person)	–	–	–	2.35 (−1.91, 6.61)	0.8 (−2.97, 4.56)
W×Average years of education attainment	–	–	–	3.62 (−2.87, 10.12)	5.34 (−1.07, 11.75)
W×Per capita public green areas (m^2 per person)	–	–	–	−4.07 $(−6.53, -1.61)^{***}$	−4.82 $(−7.13, -2.52)^{***}$
Constant	18.83 (−10.89, 48.54)	22.09 $(−3.47, 47.65)^{*}$	22.11 $(2.37, 41.85)^{**}$	4.03 (−39.51, 47.57)	−8.89 (−52.64, 34.85)
Observations	31	31	31	31	31
R^2	0.62				
Adjusted R^2	0.53				

Continued

Socioeconomic variables	Estimate (95% *CI*)				
	OLS	SLM	SEM	SDM	SDEM
Log Likelihood		−92.21	−91.79	−84.96	−85.24
sigma^2		22.13	20.41	13.83	14.23
Akaike Inf. Crit.	202.22	202.42	201.58	199.92	200.48
Residual Std. Error	5.54 (df = 24)				
F Statistic	6.59*** (df = 6; 24)				
Wald Test (df = 1)		1.62	4.85**	1.22	0.45
LR Test (df = 1)		1.79	2.64	0.83	0.26
LM Test		0.17	0.25	0.45	0.04

Note. **P* < 0.1; ***P* < 0.05; ****P* < 0.01. OLS: ordinary leas square; SLM: spatial lag model; SEM: spatial error model; SDM: spatial Durbin model; SDEM: spatial Durbin error model; *CI*: confidence interval; LM: Lagrange Multiplier; LR: Lagrange multiplier.

Supplementary Table S3-3. Socioeconomic factors of the odds of receiving antihypertensive treatment among hypertensive participants who were aware of their condition

Socioeconomic variables	Estimate (95% *CI*)				
	OLS	SLM	SEM	SDM	SDEM
Current smoker prevalence (%)	0.23 (−0.35, 0.81)	0.24 (−0.25, 0.73)	0.73 (0.36, 1.10)***	0.87 (0.59, 1.14)***	0.79 (0.47, 1.10)***
Excessive drinker prevalence (%)	−0.63 (−1.32, 0.05)*	−0.70 (−1.30, −0.10)**	−0.56 (−0.88, −0.24)***	−0.73 (−1.08, −0.37)***	−0.79 (−1.41, −0.16)**
Physical inactivity prevalence (%)	0.62* (0.01, 1.23)	0.58 (0.07, 1.10)**	1.09 (0.78, 1.41)***	0.87 (0.61, 1.13)***	0.73 (0.39, 1.07)***
GDP (10,000 yuan per person)	1.94 (−0.56, 4.44)	1.92 (−0.19, 4.02)*	4.43 (2.96, 5.90)***	3.36 (2.09, 4.63)***	2.67 (1.21, 4.14)***
Average years of education attainment	2.95 (−1.64, 7.54)	2.43 (−1.82, 6.68)	1.06 (−0.77, 2.89)	−1.32 (−3.91, 1.27)	−2.75 (−6.67, 1.18)
Number of medical technical personnel in healthcare institutions per 10,000 person	−0.08 (−0.29, 0.14)	−0.07 (−0.25, 0.10)	−0.14 (−0.27, −0.02)**	−0.05 (−0.16, 0.06)	0.05 (−0.13, 0.22)
Beds of internal medicine per 10,000 person	0.002 (−1.42, 1.43)	0.12 (−1.15, 1.38)	0.12 (−0.46, 0.69)	0.33 (−0.67, 1.34)	0.5 (−1.09, 2.10)
Old dependency ratio (sample survey) (%)	0.01 (−1.13, 1.15)	0.08 (−0.88, 1.05)	−0.84 (−1.36, −0.32)***	−0.28 (−0.85, 0.28)	0.26 (−0.44, 0.96)
W× Current smoker prevalence (%)	–	–	–	1.72 (0.95, 2.49)***	1.46 (0.40, 2.52)***
W× Excessive drinker prevalence (%)	–	–	–	−0.81 (−1.79, 0.18)	0.07 (−1.45, 1.59)
W× Physical inactivity prevalence (%)	–	–	–	2.55 (1.82, 3.27)***	1.63 (0.68, 2.59)***
W× GDP (10,000 yuan per person)	–	–	–	7.16 (4.54, 9.79)***	2.97 (−0.05, 5.98)*
W× Average years of education attainment	–	–	–	−0.17 (−5.06, 4.71)	0.25 (−7.05, 7.55)
W× Number of medical technical personnel in healthcare institutions per 10,000 person	–	–	–	0.02 (−0.23, 0.27)	0.03 (−0.32, 0.39)
W× Beds of internal medicine per 10,000 person	–	–	–	−0.83 (−2.30, 0.64)	−1.61 (−3.63, 0.40)
W× Old dependency ratio (%)	–	–	–	−2.80 (−4.11, −1.48)***	−3.58 (−5.35, −1.81)***

Continued

Socioeconomic variables	Estimate (95% *CI*)				
	OLS	SLM	SEM	SDM	SDEM
Constant	38.65 (10.84, 66.46)**	33.89 (2.54, 65.24)**	34.17 (22.68, 45.66)***	66.58 (37.03, 96.13)***	19.57 (−3.16, 42.30)*
Observations	31	31	31	31	31
R^2	0.66				
Adjusted R^2	0.54				
Log Likelihood		−89.76	−83.57	−70.96	−71.97
$sigma^2$		19.12	7.69	3.98	4.24
Akaike Inf. Crit.	199.75	201.52	189.15	179.92	181.94
Residual Std. Error	5.22 (df = 22)				
F Statistic	5.38*** (df = 8; 22)				
Wald Test (df = 1)		0.28	175.98***	77.42***	60.88***
LR Test (df = 1)		0.22	12.60***	15.87***	13.85***
LM Test		0.67	0.25	0.02*	0.01**

Note. *P < 0.1; **P < 0.05; ***P < 0.01. OLS: ordinary leas square; SLM: spatial lag model; SEM: spatial error model; SDM: spatial Durbin model; SDEM: spatial Durbin error model; *CI*: confidence interval; LM: Lagrange Multiplier; LR: Lagrange multiplier.

Supplementary Table S3-4. Socioeconomic factors of the odds of controlling BP among hypertensive participants who received antihypertensive treatment

Socioeconomic variables	Estimate (95% *CI*)				
	OLS	SLM	SEM	SDM	SDEM
Obesity prevalence (%)	−1.56 (−2.75, −0.37)**	−1.72 (−2.68, −0.76)***	−1.77 (−2.52, −1.02)***	0.19 (−0.56, 0.94)	−0.15 (−1.00, 0.69)
Current smoker prevalence (%)	−0.08 (−0.79, 0.63)	−0.08 (−0.65, 0.49)	0.16 (−0.41, 0.74)	0.52 (0.18, 0.86)***	0.39 (0.04, 0.74)**
Excessive drinker prevalence (%)	−0.5 (−1.39, 0.39)	−0.48 (−1.18, 0.23)	−0.36 (−0.96, 0.24)	−0.17 (−0.63, 0.29)	−0.15 (−0.76, 0.46)
Physical inactivity prevalence (%)	0.56 (−0.26, 1.39)	0.62 (−0.03, 1.27)*	0.69 (0.10, 1.28)**	0.55 (0.17, 0.93)***	0.71 (0.29, 1.13)***
GDP (10,000 yuan per person)	0.61 (−2.41, 3.63)	1 (−1.44, 3.43)	1.69 (−0.91, 4.29)	0.33 (−2.40, 3.06)	0.01 (−2.57, 2.60)
Average years of education attainment	0.29 (−5.84, 6.42)	0.61 (−4.31, 5.53)	−1.05 (−4.95, 2.84)	−1.19 (−4.64, 2.25)	−0.04 (−4.45, 4.37)
Per capita public green areas (m^2 per person)	0.8 (−0.26, 1.86)	0.75 (−0.09, 1.58)*	0.56 (−0.27, 1.39)	0.31 (−0.45, 1.08)	0.54 (−0.22, 1.30)
Number of medical technical personnel in healthcare institutions per 10,000 persons	0.14 (−0.14, 0.43)	0.13 (−0.09, 0.36)	0.16 (−0.08, 0.40)	0.07 (−0.18, 0.32)	0.002 (−0.29, 0.29)
Beds of internal medicine per 10,000 person	0.87 (−1.28, 3.02)	0.76 (−0.96, 2.48)	0.99 (−0.36, 2.34)	1.96 (0.69, 3.24)***	2.66 (1.08, 4.23)***

Continued

Socioeconomic variables	Estimate (95% *CI*)				
	OLS	SLM	SEM	SDM	SDEM
Old dependency ratio (sample survey) (%)	−0.57 (−1.97, 0.84)	−0.62 (−1.73, 0.50)	−0.47 (−1.41, 0.47)	−1.56 (−2.18, −0.94)***	−1.69 (−2.42, −0.96)***
W× Obesity prevalence (%)	–	–	–	−4.65 (−6.78, −2.51)***	−2.84 (−5.09, −0.60)**
W× Current smoker prevalence (%)	–	–	–	1.31 (0.41, 2.21)***	1.24 (0.13, 2.35)**
W× Excessive drinker prevalence (%)	–	–	–	−1.20 (−2.46, 0.07)*	−0.69 (−2.42, 1.03)
W× Physical inactivity prevalence (%)	–	–	–	1.41 (0.40, 2.42)***	0.76 (−0.56, 2.09)
W× GDP (10,000 yuan per person)	–	–	–	8.51 (3.67, 13.35)***	6.35 (1.36, 11.34)**
W× Average years of education attainment	–	–	–	−1.64 (−9.11, 5.82)	−0.4 (−9.19, 8.39)
W× Per capita public green areas (m^2 per person)	–	–	–	−2.83 (−5.20, −0.46)**	−3.75 (−6.74, −0.76)**
W× Number of medical technical personnel in healthcare institutions per 10,000 person	–	–	–	0.27 (−0.17, 0.72)	0.28 (−0.21, 0.78)
W× Beds of internal medicine per 10,000 person	–	–	–	1.41 (−0.89, 3.71)	−0.78 (−3.35, 1.79)
W× Old dependency ratio (%)	–	–	–	1.57 (−0.01, 3.15)*	1.72 (−0.18, 3.62)*
Constant	14.45 (−23.23, 52.13)	19.15 (−13.14, 51.43)	12.47 (−12.98, 37.91)	−18.59 (−80.26, 43.07)	−27.94 (−84.87, 28.99)
Observations	31	31	31	31	31
R^2	0.54				
Adjusted R^2	0.31				
Log Likelihood		−93.7	−92.47	−70.17	−71.04
$sigma^2$		24.42	20.5	4.9	4.34
Akaike Inf. Crit.	212.23	213.41	210.94	186.34	188.08
Residual Std. Error	6.27 (df = 20)				
F Statistic	2.37** (df = 10; 20)				
Wald Test (df = 1)		0.93	8.37***	9.39***	34.85***
LR Test (df = 1)		0.82	3.29*	6.34**	4.60**
LM Test		0.41	0.26	0.46	0.29

Note. *P < 0.1; **P < 0.05; ***P < 0.01. OLS: ordinary leas square; SLM: spatial lag model; SEM: spatial error model; SDM: spatial Durbin model; SDEM: spatial Durbin error model; *CI*: confidence interval; LM: Lagrange Multiplier; LR: Lagrange multiplier.