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# The National Sarcopenia Atlas of China: Geospatial Patterns and Region-Specific Cardiorenal Risks Among Middle-Aged and Older Adults

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Research Article

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## Abstract

### Background

Sarcopenia is a global challenge and a potential modifiable risk factor for cardiorenal diseases. However, the geospatial variation of sarcopenia in China and its region-specific associations with cardiovascular disease (CVD) and chronic kidney disease (CKD) remain poorly defined.

### Methods

We analyzed participants aged over 45 years from the China Health and Retirement Longitudinal Study (CHARLS, 2011–2020). Sarcopenia was defined by AWGS 2019 criteria. Spatial autocorrelation analysis (Moran's I) identified provincial clustering. Region-stratified longitudinal logistic regression assessed associations between baseline sarcopenia and incident CVD and CKD during a median 9.0-year follow-up.

### Results

Among 12,263 participants (52.1% female; 27.4% aged over 65), spatial autocorrelation analysis identified significant 'High-High' sarcopenia clustering in Southwest China ($P < 0.05$), contrasting with 'Low-Low' clustering in Northern and Northeastern China ($P < 0.05$). In Southwest China, baseline sarcopenia was significantly associated with increased risk of incident CVD (OR 1.58, 95% CI 1.08–2.32, $P < 0.05$) and CKD (OR 1.76, 95% CI 1.17–2.63, $P < 0.01$). Notably, these longitudinal associations were not statistically significant in national-level analyses (CVD: OR 1.11, $P = 0.40$; CKD: OR 1.28, $P = 0.09$) or other regions.

### Conclusions

This study provides the first national sarcopenia atlas for China, revealing significant geographic clustering and region-stratified associations with cardiorenal diseases. The increased risk specifically in Southwest China highlights the necessity for region-specific public health strategies and resource allocation for sarcopenia management.

## Introduction

Sarcopenia is an age-related skeletal muscle disorder characterized by the progressive attrition of muscle mass, strength, and physical function, and often culminating in adverse clinical outcomes in middle-aged and older adults [1]. Emerging evidence indicates that the prevalence of sarcopenia exceeds one-fifth among adults aged 60 and older, with a rising trend since 2019 [2], which represents a substantial public health and socioeconomic challenge. Beyond compromising individual quality of life, burden of sarcopenia escalates healthcare utilization and expenditure by driving functional dependency and related complications [2, 3].

Nevertheless, the distribution of disease burden often demonstrates marked regional heterogeneity, particularly in regions with a vast geographic span [4, 5]. In China, regional heterogeneity is pronounced given the pronounced variation in climate, sunlight exposure, socioeconomic conditions and lifestyle patterns, which have been shown to influence the distribution of multiple chronic diseases [6, 7]. We have recently identified significant spatial heterogeneity in dementia prevalence at provincial level, underscoring the necessity for region-specific risk assessment and tailored public health interventions [8]. Regarding sarcopenia, a recent systematic review of 45 studies provided preliminary evidence of a North–South gradient in China, with a marginally higher prevalence observed in Southern regions (21·7%) compared to the North (19.0%) [2]. Despite these aggregate observations suggesting a non-uniform distribution of sarcopenia prevalence, a comprehensive nationwide, province-level atlas of sarcopenia remains to be established. Consequently, the granular spatial clustering patterns and their longitudinal associations with incident complications remain poorly characterized.

Of note, sarcopenia is increasingly recognized as a potentially modifiable risk factor for systemic diseases [9]. Longitudinal investigations have demonstrated dynamic dose-response relationships between the progression of

sarcopenia and elevated risks of cardiovascular diseases (CVD) [10], whereas muscle recovery attenuated adverse events [11]. Furthermore, corroborating evidence confirms that sarcopenia independently increases the risk of incident chronic kidney diseases (CKD) [12]. However, current literature is largely constrained by national or broad-scale aggregate estimates to characterize these associations, which may obscure latent geographic heterogeneity. Consequently, it remains undetermined whether sarcopenia prevalence clusters within specific regions and, if so, whether the associated cardiorenal burden is disproportionately concentrated in these high-risk areas. Importantly, given that both CVD and CKD are leading contributors to global morbidity and mortality in China, early identification of modifiable risk factors (i.e. sarcopenia) is pivotal for public health advancement [7, 13].

To bridge this gap, we estimated the weighted provincial prevalence of sarcopenia leveraging data from the China Health and Retirement Longitudinal Study (CHARLS), a nationally representative cohort of middle-aged and older adults [14]. Specifically, we aimed to: (1) characterize spatiotemporal patterns of sarcopenia by employing spatial autocorrelation analysis to identify regional clustering, and (2) evaluate the longitudinal associations between sarcopenia and incident CVD and CKD through region-stratified analyses. Our findings are expected to generate the first geographic atlas for sarcopenia across China, reveal the region-stratified association between sarcopenia and incident cardiorenal diseases, and inform region-specific resource allocation strategies.

# Method

### Study population

The CHARLS is a nationally representative longitudinal survey of Chinese adults aged ≥45 years, employing multi-stage stratified probability-proportional-to-size (PPS) sampling across 150 counties/districts and 450 villages/communities in 28 provinces [14]. Data were collected biennially via computer-assisted personal interviews (CAPI), incorporating physical measurements, biospecimen collection, and chronic disease surveillance. Five waves have been publicly released (baseline 2011, follow-ups 2013, 2015, 2018 and 2020). The CHARLS project was approved by the Biomedical Ethics Committee of Peking University (IRB00001052-11015), with all participants providing written informed consent.

To ensure national representativeness, survey weights were constructed following CHARLS guidelines [14]. For longitudinal analyses, baseline sampling weights with non-response adjustments were derived using inverse probability weighting, truncated at the 99th percentile to mitigate the influence of outliers. For cross-sectional analyses, wave-specific weights accounting for attrition (mortality and loss to follow-up) were applied.

The analytical cohort contained two components (**Figure 1**). For the cross-sectional geospatial analysis, we utilized data from three waves (2011, 2013, 2015). Participants aged <45 years or with missing sarcopenia diagnostics were excluded, yielding analytical samples of n=12,263 (2011), n=8,051 (2013), and n=8,626 (2015). For the longitudinal analysis of incident outcomes, the 2011 wave served as the baseline (n=10,863); participants with missing follow-up data or pre-existing CVD and CKD at baseline were excluded.

### Assessment of sarcopenia

Sarcopenia was assessed based on the 2019 Asian Working Group for Sarcopenia (AWGS) algorithm [15], defined as the presence of low appendicular skeletal muscle mass, plus either low muscle strength or low physical performance. The specific assessment methods and cut-off values were as follows.

Muscle strength was assessed by measuring handgrip strength (kg) using a dynamometer. Measurements were taken bilaterally, and the highest value from duplicate maximal-effort tests with the elbow flexed at 90° was recorded. If a measurement from one side was unavailable, the value from the contralateral side was used. Low muscle strength was defined as a handgrip strength of < 28 kg for men and < 18 kg for women.

Appendicular skeletal muscle mass (ASM) was estimated using a validated Chinese-specific anthropometric equation: $\text{ASM (kg)} = 0.193 \times \text{weight (kg)} + 0.107 \times \text{height (cm)} - 4.157 \times \text{gender (1 for male, 2 for female)} - 0.037 \times \text{age (years)} - 2.631$. Low muscle mass was defined as an ASM index (ASM/height$^2$) of <7.0 kg/m$^2$ for men and <5.4 kg/m$^2$ for women. This equation has been previously demonstrated to show strong agreement with dual-energy X-ray absorptiometry (DXA) as the reference standard [16].

Physical performance was evaluated using two tests: (1) Gait speed: Participants were timed during a 2.5-meter walk at their usual pace. A speed of <1.0 m/s was indicative of low physical performance; (2) Five-repetition chair stand test: Participants were asked to stand up five times consecutively from a standard-height chair (47 cm) as quickly as possible with their arms crossed over their chest. A completion time of ≥12 seconds was defined as low physical performance.

### Ascertainment of Incident cardiovascular diseases (CVD) and chronic kidney diseases (CKD)

Outcomes were defined as incident CVD or CKD occurring between 2013 and 2020. Incident CVD was defined as a composite of physician-diagnosed heart disease or stroke reported in any follow-up wave (2013, 2015, 2018, or 2020) among participants free of CVD at baseline. Incident CKD was defined as a self-reported physician diagnosis of kidney disease in follow-up waves among participants free of CKD at baseline. Self-reported diagnoses in CHARLS have been previously validated against clinical records [17,18].

### Assessment of covariates

Data on demographic characteristics, lifestyle factors, and prevalent comorbidities were collected at baseline (2011) through standardized questionnaires administered during face-to-face interviews. Demographic and lifestyle variables included age, sex, annual household income (categorized into quartiles, with the lowest quartile Q1 as reference), educational attainment (classified as less than upper secondary, upper secondary, or tertiary, using “less than upper secondary” as reference), and area of residence (urban or rural). Smoking status was categorized as never smoker, former smoker, ever smoker (current status uncertain), or current smoker (reference: never smoker). Alcohol consumption was classified based on the frequency of drinking in the preceding year: never, ≤1 time per week, or >1 time per week (reference: ≤ 1 time per week). Physical inactivity was defined according to guidelines from the International Physical Activity Questionnaire (IPAQ), referring to previous studies [19]. Participants were considered physically inactive if they did not meet any of the following criteria for moderate-level physical activity per week: (a) ≥ 3 days of vigorous-intensity activity lasting ≥ 20 minutes per day; (b) ≥ 5 days of moderate-intensity activity and/or walking lasting ≥ 30 minutes per day; or (c) ≥ 5 days of any combination of walking and moderate- or vigorous-intensity activities accumulating ≥ 600 MET-minutes/week (reference: physically active). Prevalent comorbidities, including hypertension, dyslipidemia, and diabetes, were diagnosed based on self-reported physician diagnoses.

### Statistical analysis

Statistical analysis was conducted in three phases to examine the spatiotemporal patterns of sarcopenia and its determinants.

First, we estimated the age-standardized prevalence of sarcopenia for 28 provinces using data from 2011-2015. Rates were aggregated and visualized using geographic coordinates from the National Geospatial Information Platform (http://www.tianditu.com/).

Second, spatial autocorrelation analysis was performed to identify clustering patterns. Global Moran’s I [20] was computed to assess overall spatial dependence, depicting attribute similarity between adjacent spatial units. Subsequently, local indicators of spatial association (LISA), specifically Local Moran’s I [21], were applied to detect regional clustering. Positive values indicate spatial clusters of similar rates (“High-High” or “Low-Low”), whereas negative values suggest spatial outliers (“High-Low” or “Low-High”). Significance was evaluated using analytical approximations based on normal distribution theory, with $P < 0.05$ considered statistically significant.

Third, survey-weighted logistic regression models were fitted to examine associations between baseline sarcopenia (2011 wave) and incident CVD/CKD by 2020. Region-specific models were constructed using the full survey design framework, incorporating sampling weights, stratification by urban-rural residence, and clustering within primary sampling units. Adjustments for singleton clusters were applied to accommodate geographically isolated units, and quasi-binomial regression was used to address overdispersion and yield robust standard errors. Models were adjusted for sociodemographic characteristics (age, sex, education, income), health behaviors (smoking, alcohol, sleep), and physical inactivity. Region-specific odds ratios (ORs) with 95% confidence intervals (CIs) were estimated to quantify geographic effect modification. Regions with insufficient outcome variability were excluded to ensure model stability [8].

All analyses were conducted in R version 4.5.1 using specialized packages including sp, sf, and ggplot2 for geospatial operations.

# Results

### Characteristics of participants at baseline (wave 2011)

A total of 12,263 participants ≥ 45 years old from 28 provinces in China with long-term follow-up (median: 9.0 years) were included at baseline (**Figure 1**). All provinces were grouped into seven geographic regions including the Northeast, North, East, South, Central, Northwest, and Southwest China (**Supplementary Figure 1**), and baseline characteristics of the study population across regions are summarized in **Table 1**. In 2011, 52.1% of participants were female, and 27.4% were aged 65 years or older. Overall, 2,387 participants (19.5%) were identified as sarcopenia. Additional sociodemographic, lifestyle, and clinical characteristics at baseline in 2011, as well as corresponding regional characteristics in 2013 and 2015, are presented in **Supplementary Tables 1-3**.

Marked regional variation in sarcopenia prevalence was observed that the highest weighted prevalence was found in the Southwest region (27.0%, n = 610), whereas the North (10.5%, n = 149) and Northeast (14.8%, n = 137) regions exhibited the lowest prevalence. Sarcopenia prevalence in the remaining regions ranged from 18.3% to 20.5% (**Table 1**). From 2011 to 2015, the weighted prevalence in the Southwest region remained relatively stable, while other regions showed temporal fluctuations (**Supplementary Figure 2**). Across all regions, sarcopenia prevalence increased progressively with advancing age, and similar age-related patterns were consistently observed across geographic regions (**Supplementary Figures 3-5**).

### Spatiotemporal patterns of sarcopenia across China

To characterize the geospatial distribution pattern of provincial sarcopenia prevalence, we performed province-specific mapping and spatial autocorrelation analyses. Across three waves (2011, 2013, and 2015), spatial distribution maps visualized a persistently high sarcopenia prevalence in the Southwest region (Yunnan, Chongqing, Guizhou, Sichuan). By contrast, the lower rates were both observed in the Northeast (Heilongjiang, Jilin, Liaoning) and North region (**Figure 2a, c, e**).

Applying spatial autocorrelation analyses, positive/negative correlations and spatial clustering were identified. LISA revealed significant “High-High” clustering ($P < 0.05$) of sarcopenia prevalences, which was majorly concentrated in the Southwest region, whereas areas with “Low-Low” clustering ($P < 0.05$) were primarily located in the Northeast and North regions, respectively (**Figure 2b, d, f**). These findings revealed significant geographic disparities across China, and a highly clustered pattern of sarcopenia prevalence in the Southwest.

### Region-specific longitudinal associations of sarcopenia with incident CVD and CKD

To investigate whether cardiorenal disease exhibit similar geographic clustering with sarcopenia or not, we employed region-stratified analyses to evaluate potential longitudinal associations between sarcopenia and incident CVD or CKD with weighting. After excluding 1,400 participants with missing data on age, sex, education, annual income, smoking, drinking, residence place, hypertension, dyslipidemia, or diabetes, a total of 10,863 participants were included in the longitudinal analyses (**Figure 1, Supplementary Table 4**).

Regarding CVD, individuals with sarcopenia in the Southwest regions were significantly associated with the risk of incident CVD even after adjustment for age, sex, education, income, smoking status, drinking frequency, sleep duration, and physical inactivity (OR = 1.58, 95% CI: 1.08–2.32; **Figure 3a, Supplementary Table 4**), whereas these associations were not observed in the whole nation or in other regions. Similarly, sarcopenia was significantly associated with the risk of CKD among individuals in the Southwest region (OR = 1.76, 95% CI: 1.17–2.63; **Figure 3b, Supplementary Table 4**), whereas no significant association was observed at the national level or in other regions. Collectively, these findings suggested that the marked geographic clustering of sarcopenia in Southwest China is positively associated with elevated risks of cardiovascular and renal complications, demonstrating their distinct geographic heterogeneity.

# Discussion

To our best knowledge, this is the first nationwide geospatial analysis to systematically characterize the geographic disparities in sarcopenia burden and its associated cardiorenal outcomes across China. Our analysis identified a distinct bimodal distribution, characterized by persistent 'High-High' clustering in the Southwest and 'Low-Low' clustering in Northern China. Crucially, region-stratified models revealed significant geographic effect modification that populations in the Southwest concurrently exhibit a higher prevalence of sarcopenia and a significantly heightened risk of incident cardiovascular and chronic kidney diseases over long-term follow-up. These data suggest that subnational heterogeneity is a fundamental yet overlooked dimension of sarcopenia epidemiology. By uncovering these hidden disproportionate burden in vulnerable regions, our findings provide advanced evidence for transitioning from generalized interventions to targeted, subnational health strategies.

The regional variations observed in current study likely stem from a multifaceted synergy between dietary habits, socioeconomic status, and environmental constraints. In Southwest China, traditional dietary patterns characterized by higher intake of sodium and oils coupled with lower consumption of high-quality protein (compared to Northern diets) may contribute to the pathogenesis of muscle loss and sarcopenia [22, 23]. This geographic clustering might be further compounded by socioeconomic disparities because the rural area in Southwestern regions often face more constrained healthcare infrastructure and lower per capita income, creating a milieu conducive to musculoskeletal decline [24]. Beyond lifestyle and economics, the unique climate of the Sichuan Basin and Yunnan-Guizhou Plateau, marked by sustained humidity and low sunlight exposure, may also limit regular outdoor physical activity and endogenous vitamin D synthesis [25, 26].

Notably, the observed geographic clustering of sarcopenia aligns closely with the shifting regional epidemiology of cardiorenal disease in China. Although cardiovascular burden has historically been perceived as Northern-predominant [27], recent surveillance data indicate a rapid escalation of cardiometabolic risk in the Southwest. Specifically, the China Kidney Disease Network (CK-NET) has identified the Southwest as a prominent hotspot for chronic kidney disease, reporting a prevalence rate of 18.3%, which was significantly higher than the national average (10.8%) [28]. Furthermore, longitudinal evidence reveals that rural Southwest China has witnessed the fastest growth in the clustering of cardiovascular risk factors (e.g., hypertension and central obesity) over the past decade [29]. This epidemiological convergence combing with current longitudinal findings collectively indicates that sarcopenia does not merely coexist with these conditions but may exacerbate outcomes within an already vulnerable population. Taken together, from a public health perspective, these findings challenged the utility of a uniform, national public health approach and highlight the importance of region-specific preventive strategies in Southwest region that it should enhance screening for CVD and CKD among individuals with sarcopenia to facilitate earlier risk identification and integrated management.

Several study strengths merit acknowledgment. First, this is the first geospatial analysis of sarcopenia leveraging nationally representative data. Second, the coupling of spatial autocorrelation with region-stratified longitudinal modeling offers a robust framework for disentangling the geographic heterogeneity of sarcopenia and its associated complications. Last, the adoption of the AWGS 2019 diagnostic criteria, combined with rigorous survey weighting, ensures that our findings maintain high generalizability and population-level validity.

Several limitations also warrant interpretation in context. First, despite national representativeness, CHARLS samples exclusively Chinese adults, which is predominantly Han Chinese population, potentially limiting generalizability to other ethnic groups. Second, although several provinces were omitted due to incomplete data, these areas are primarily sparsely populated regions in Western China; thus, their exclusion is unlikely to have introduced substantial bias or compromised the robustness of our primary conclusions. Third, sarcopenia assessments in CHARLS were discontinued after year 2015. Finally, the incidences of CVD and CKD were ascertained through self-reported physician diagnosis, which may underrepresent asymptomatic disease. Future studies incorporating objective adjudication would strengthen causal inference.

## Conclusions

In conclusion, current nationwide geospatial study demonstrates that the burden of sarcopenia and correlated cardiorenal diseases exhibit pronounced geographic heterogeneity across China. Public health priorities may be encouraged to designate the Southwest region as a high-priority zone for sarcopenia in middle-aged and older people to preferentially screen CVD and CKD at early-stage.

## Abbreviations

CVD

Cardiovascular disease

CKD

Chronic kidney disease

CHARLS

China Health and Retirement Longitudinal Study

PPS

Probability-proportional-to-size

CAPI

Computer-assisted personal interviews

AWGS

Asian Working Group for Sarcopenia

ASM

Appendicular muscle mass

DXA

Dual-energy X-ray absorptiometry

IPAQ

International Physical Activity Questionnaire

LISA

Local indicators of spatial association

CK-NET

the China Kidney Disease Network

OR

Odd ratio

95% CI

95% Confidence interval

## Declarations

### Ethics approval and consent to participate

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Biomedical Ethics Committee of Peking University (IRB00001052-11015). Informed consent was obtained from individual participants in the study. Besides, the accessed patient data complied with relevant protection, privacy guidelines and regulations.

### Consent for publication

Not applicable.

### Availability of data and materials

The paper and the supporting information present all the data needed to evaluate the conclusions. Datasets used and/or analyzed during the current study are available from the CHARLS project (http://charls.pku.edu.cn/en) or from the corresponding author on reasonable request.

### Competing interests

The authors declare no competing interests.


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### Authors' contribution

XS Wang, J Liao and CH Ding contributed to the conception of the study and the study design, and obtained the research funding to support this study and provided continual supervision. YJ Huang, J Li and HW Chen contributed to the data curation and the statistical analyses. TY Chen, WH Liu and GF Ruan contributed to the design and examination of the code. Zhong Alan Li and J Liu contributed to the interpretation of the data. YJ Huang, J Li and HW Chen accessed and verified the data, wrote the initial version of the manuscript. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.


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# Table

**Table 1. Demographic characteristics of different geographic regions at baseline (wave 1, 2011)**

| Variable | N | Overall N = 12,263[a] | Central N = 2,162[a] | East N = 3,874[a] | North N = 1,417[a] | Northeast N = 924[a] | Northwest N = 925[a] | South N = 702[a] | Southwest N = 2,259[a] |
|---|---|---|---|---|---|---|---|---|---|
| **Age group** | 12,263 | | | | | | | | |
| *45-65* | | 8,905 (72.6%) | 1,569 (72.6%) | 2,763 (71.3%) | 1,131 (79.8%) | 708 (76.6%) | 683 (73.8%) | 504 (71.8%) | 1,547 (68.5%) |
| *≥65* | | 3,358 (27.4%) | 593 (27.4%) | 1,111 (28.7%) | 286 (20.2%) | 216 (23.4%) | 242 (26.2%) | 198 (28.2%) | 712 (31.5%) |
| **Sex** | 12,263 | | | | | | | | |
| *Female* | | 6,392 (52.1%) | 1,134 (52.5%) | 2,033 (52.5%) | 730 (51.5%) | 497 (53.8%) | 475 (51.4%) | 369 (52.6%) | 1,154 (51.1%) |
| *Male* | | 5,871 (47.9%) | 1,028 (47.5%) | 1,841 (47.5%) | 687 (48.5%) | 427 (46.2%) | 450 (48.6%) | 333 (47.4%) | 1,105 (48.9%) |
| **Sarcopenia** | 12,263 | | | | | | | | |
| *No* | | 9,876 (80.5%) | 1,753 (81.1%) | 3,165 (81.7%) | 1,268 (89.5%) | 787 (85.2%) | 735 (79.5%) | 519 (73.9%) | 1,649 (73.0%) |
| *Yes* | | 2,387 (19.5%) | 409 (18.9%) | 709 (18.3%) | 149 (10.5%) | 137 (14.8%) | 190 (20.5%) | 183 (26.1%) | 610 (27.0%) |

[a]Continuous variables: Mean (SD); Categorical variables: n (%)

# Figures

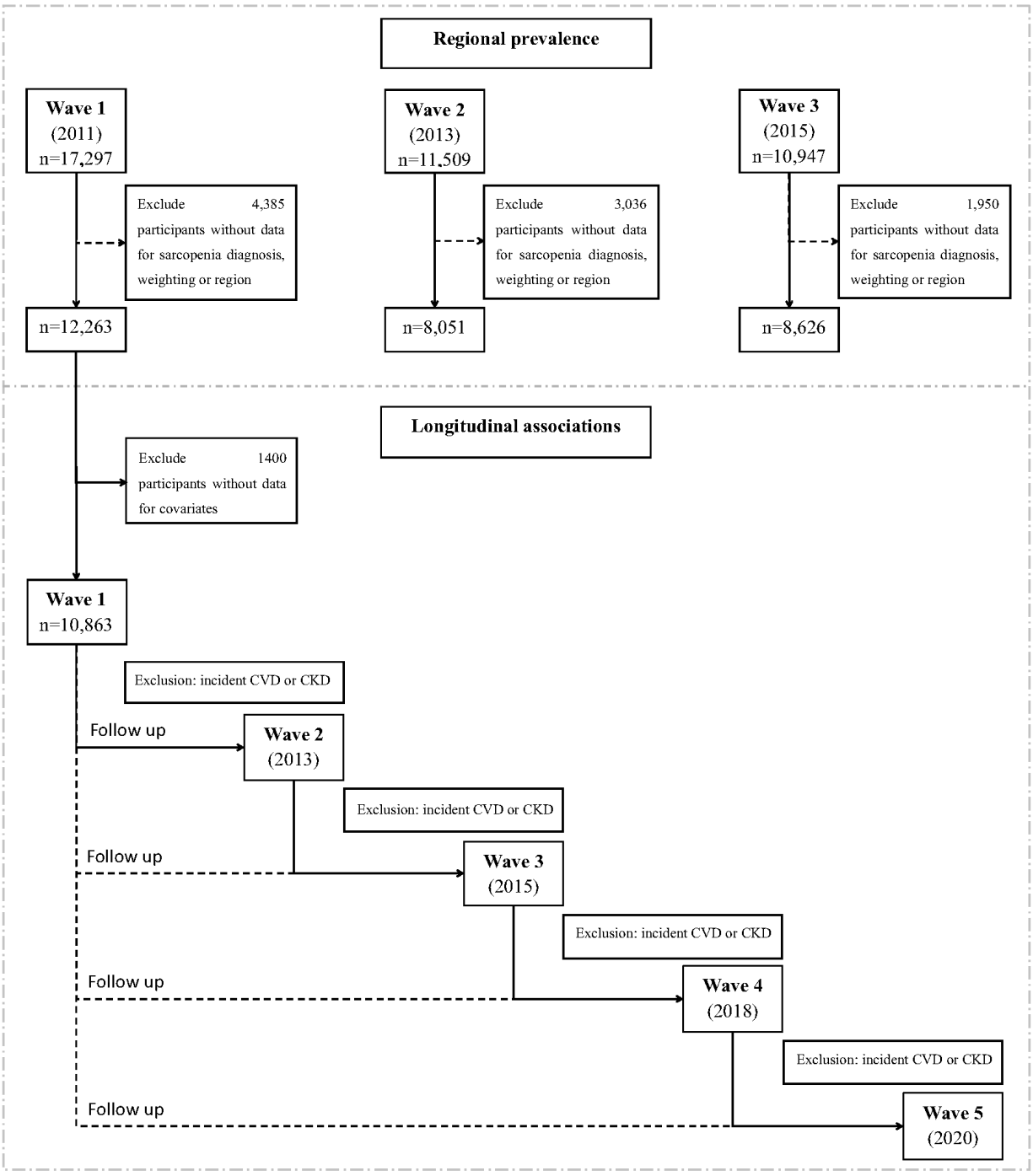



Figure 1

**Study flowchart of the sample selection process**

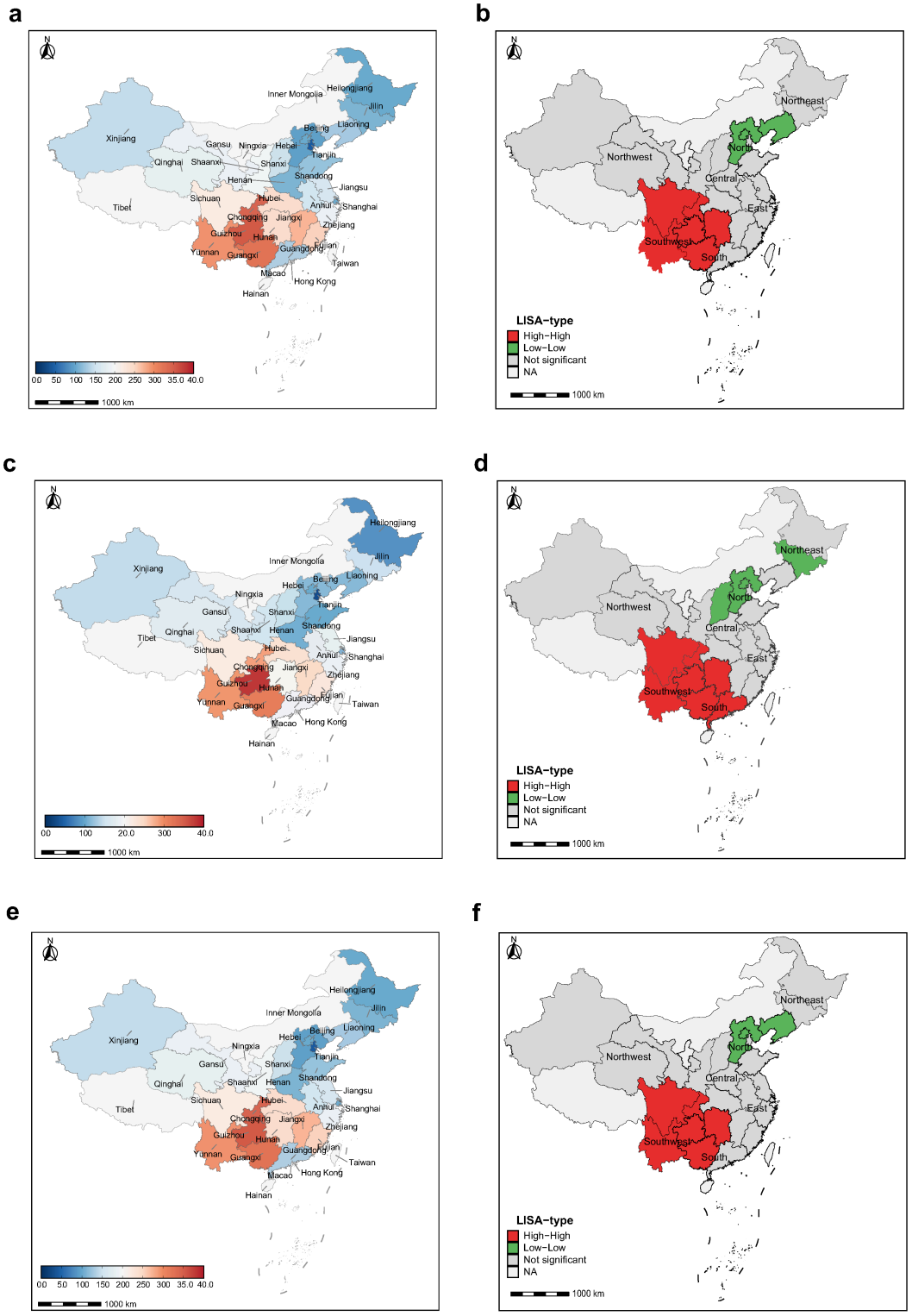



Figure 2

**Provincial maps of the weighted prevalence of sarcopenia.** The estimated prevalence represents the weighted distribution for sarcopenia of wave (a) 2011, (c) 2013, (e) 2015. Corresponding spatial autocorrelation analysis for wave (b) 2011, (d) 2013, (f) 2015 were also displayed, respectively.

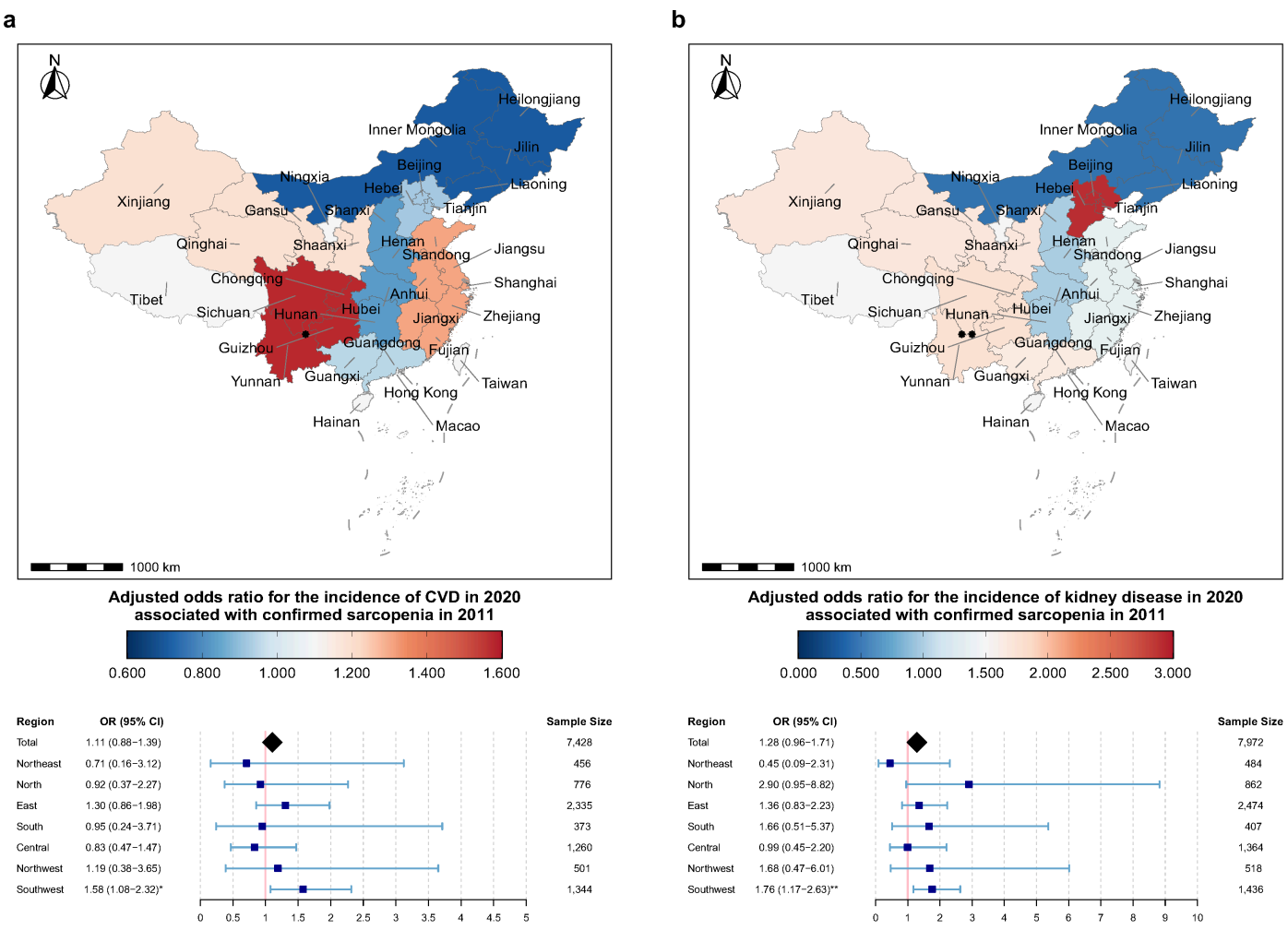



Figure 3

**Spatial mapping of region-specific regression coefficients for the associations between baseline sarcopenia and incident** (a) CVD and (b) CKD. CVD, cardiovascular disease; CKD, chronic kidney disease; *, P<0.05; **, P<0.01

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalfile1.docx