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The Influence of New-Type Urbanization and Environmental Pollution on Public Health: A Spatial Durbin Model Study

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Abstract: The rapid pace of urbanization in recent years, accompanied by the tension between urbanization and environmental pollution as well as public health, has become increasingly prominent, potentially constraining the normal pace of urbanization development, environmental sustainability and public health enhancement. This paper aims to clarify the relationship between new urbanization, environmental pollution and public health from both local and spatial perspectives, using a spatial Durbin model and a mediating effects model based on panel data from 275 prefecture-level cities in China from 2011 to 2020 and to test the existence of regional heterogeneity with a sub-sample of three major regions: eastern, central and western China. After incorporating environmental pollution as a variable across the entire scope of China, it was found that the new-type urbanization was related to public health in a 'positive U-shaped' form in terms of both local and spatial spillover effects ($\beta_2 = 14.5620$, $\beta_3 = -17.8938$, $p < 0.05$; $\theta_2 = 19.2527$, $\theta_3 = -29.0973$, $p < 0.1$) and environmental pollution exerts a negative impact on public health ($\beta_1 = 6.3704$, $\theta_1 = 2.5731$, $p < 0.05$). A "reverse U-shaped" local effect was observed between new-type urbanization and environmental pollution ($\beta_2 = 0.6281$, $\beta_3 = -0.5315$, $p < 0.05$). Environmental pollution plays a partially mediating role in the impact mechanism of new-type urbanization on public health. There was regional heterogeneity in the relationship between new-type urbanization, environmental pollution and public health. The empirical results for the western regions and the whole of China were generally consistent, but the differences were significant between the eastern and central regions. In the eastern region, new-type urbanization and public health were related in an 'inverted U-shaped' form from the perspective of local and spatial spillover effect, and in the central region, there was an 'inverted U-shaped' form from the perspective of local effect. There was a threshold effect relationship between new-type urbanization and environmental pollution and between new-type urbanization and public health. At the same time, there was regional heterogeneity in the relationships between the three. Therefore, this paper argues that governments should formulate scientific urban planning and sustainable development policies that take into account the actual situation of each region and aim to promote sustainable urbanization, environmental quality and public health as a whole.

Keywords: new-type urbanization; environmental pollution; public health; spatial Durbin model

Citation: Wu, K.; Wang, R.; Zhang, Y.; Wu, R.; He, Y.; Li, B.; Zhang, Y. The Influence of New-Type Urbanization and Environmental Pollution on Public Health: A Spatial Durbin Model Study. *Sustainability* **2023**, *15*, 16144. https://doi.org/10.3390/su152316144

Academic Editor: Elena Cristina Rada

Received: 2 September 2023
Revised: 6 November 2023
Accepted: 9 November 2023
Published: 21 November 2023

1. Introduction

Urbanization is a process through which people engaged in agricultural activities migrate to towns and cities [1]. The world is experiencing the largest wave of urbanization in its history. According to United Nations reports, 55% of the world's population currently lives in urban areas and by 2050, 68% of the population is expected to be urban dwellers [2]. Urbanization is a double-edged sword for public health, providing so-called 'urban advantages' [3] such as increased access to health care, sanitation, safe nutrition, education and employment opportunities, but also certain 'urban penalties such as increased exposure to health risks such as environmental pollution, unhealthy diets, sedentary lifestyles, life stress, road traffic injuries and traffic noise' [4]. Among the 'urban penalties', environmental pollution has been shown to have a significant negative impact on public health [5]. For instance, China has experienced decades of swift urbanization along with its industrial modernization, with the trade-off being the deterioration of the environment. According to the 2018 Global Environmental Performance Index, jointly published by Columbia University and Yale University, China's environmental performance index score is 50.74, placing it 120th out of 180 countries in the world participating in the ranking, and fourth from the bottom in terms of environmental quality assessment [6]. The figures point directly to one of the fallouts of urbanization, the environmental pollution in the country, which remarkably contributes to urbanization-induced industrial development, energy consumption and urban traffic overload.

China's urbanization has grown rapidly over the last three decades and is still in the process of rapid urbanization. In 2020, the urbanization rate of the country was 63.89% and is expected to reach 70.12% by 2030 [7]. During the first stage of urbanization, China mainly followed the path of "high consumption, high emission" to urbanization, which undoubtedly posed a huge challenge to the ecological environment, such as the memorable "APEC Blue" in Beijing in 2014 [8]. From the perspective of urbanization development, China remains in the second stage of urbanization, in contrast to developed countries, which have advanced to the third stage. China's urbanization has a considerable distance to cover. In response, the Chinese government introduced the "National New-Type Urbanization Plan (2014–2020)" with the principles of "people-centered" and "equitable sharing". New-type urbanization encompasses various themes, including population concentration, land use, income enhancement, equalization of public services, and cultural heritage [9]. Traditional urbanization in China predominantly focused on the expansion of urban quantity and scale, often overlooking urbanization quality. In contrast, new-type urbanization places greater emphasis on universal access to social public services, fostering service-based economies, integrating local culture with urban development, promoting ecological environmental conservation, and innovating urban–rural management, all centered around equality, happiness, health and a green economy [10]. The State Council has implemented a series of policies outlining the specific pathways for new-type urbanization. This includes objectives such as "actively promoting the urbanization of agricultural transfer population". Additionally, measures like expediting the implementation of household registration system reforms, comprehensive adoption of the residence permit system, achieving universal coverage of basic public services for urban residents, and accelerating the establishment of a citizen-driven incentive mechanism for the agricultural transfer population have been introduced [11]. With the introduction of the new-type urbanization concept and the continuous improvement in urbanization quality, it remains uncertain whether the relationship between urbanization and environmental pollution, as well as its impact on public health, has changed.

To address these uncertainties, we present three key questions: (1) What are the mechanisms by which new-type urbanization affects environmental pollution and public health? (2) Does environmental pollution mediate the impact of urbanization on public health? (3) What are the effects of urbanization and environmental pollution on the public health levels of local and surrounding areas? The scientific answers to these questions hold substantial practical significance and reference value for Chinese policymakers and are worthy of exploration. To investigate these questions, this study employs a spatial Durbin model and integrates it with a mediation effects model.

2. Review of the Literature

Despite the growing literature on new-type urbanization, environmental pollution and public health, the majority of the studies only examine the pairwise relationships among the three variables, with there being a need for systematic analyses that include the effect of all three factors. Thus far, the relevant studies can be broadly classified into three categories as follows.

2.1. Impact of Urbanization on Environmental Pollution

There is still no consensus on the dynamic and complex relationship between urbanization and environmental pollution. Up to now, scholars and policy makers have reached two main conclusions concerning their relationship. One is that the correlation between the two is linearly positive or negative [12,13]. Scholars advocating the viewpoint that urbanization positively affects environmental pollution argue that rapid urbanization leads to increased energy consumption, which in turn worsens air pollution, but this situation mostly happens in the early stages of urbanization [12,14,15]. Scholars endorsing the perspective that urbanization negatively influences environmental pollution insist that urbanization increases the utilization of public facilities and transport, creates industrial agglomeration, reduces the cost of pollution control, and thus helps reduce pollution emissions [13]. The other is that the relationship between them is non-linear [16], which is attributed to the validation of the EKC (Environmental Kuznets Curve) curve hypothesis in economic, ecological and cultural fields, so that a large number of scholars have established urbanization indicators by constructing the primary, secondary, tertiary terms as well as higher coupling, so as to clarify their relationship under the EKC curve. Controversially, some scholars believe environmental pollution and urbanization have an ‘inverse U-shaped’ relationship [17–20], while some report a ‘positive U-shaped’ relationship [21], with others obtaining an ‘N-shaped’ form relationship [22].

2.2. The Impact of Urbanization on Public Health

There is growing evidence that urbanization impacts public health in two different ways [23]. On the one hand, urban living has facilitated access to modern medicine and increased the income available for healthcare and on the other hand, the health of urban dwellers is being threatened by high levels of air pollution [24], high-fat diets [25], and overcrowding [26]. Therefore, although the impact of urbanization on public health has been widely studied, their relationship is still somewhat controversial. The majority of scholars have concluded that urbanization has a negative linear effect on public health [27–29], from their findings that urbanization promoted public exposure to disease risks, including both communicable diseases [30] and non-communicable diseases [31]. Some other researchers, on the contrary, endorse its positive contribution to public health. For example, Jiang et al. [32] used a panel threshold regression model to examine the relationship between urbanization rates and mortality in the inland provinces of China, finding that urbanization had a positive impact on population health indicators [33]. However, the notion that urbanization impacts public health in a linear way is consistently unconfirmed. For example, Chen et al. [34] used nationwide data from the 2014 China Labour Force Dynamics Survey to analyze the impact of urbanization and economic development on health in China, finding an ‘inverted U-shaped’ relationship between self-measured health status and urbanization rates for both high- and low-income groups.

2.3. Impact of Environmental Pollution on Public Health

A consensus on the negative effects of environmental pollution on public health has been reached among public health scholars. A review of previous studies reveals that there are two categories of literature on the impact. The first focuses on the relationship between environmental pollution and public health from the scope of environmental science and medicine [35–37]. For example, a cross-sectional study in China on the association between air pollutants and respiratory diseases showed that exposure to environmental nitrogen dioxide during pregnancy and early life was a risk factor for diseases such as physician-diagnosed asthma, allergic rhinitis and pneumonia in children [38]. Another study by Pothirat et al. [39] found that seasonal air pollutants such as PM2.5, SO_2 and NO_2 were associated with high mortality rates among hospitalized patients and community residents, along with differential effects on severe acute respiratory disease, cardiovascular disease and cerebrovascular disease. Moreover, a study by Pierangeli et al. [40] also concluded that up to 1230 (48%) asthma cases in Barcelona each year can be attributed to air pollution. The second strand of literature examines the relationship between the two, mainly in the social and economic spheres [5,41]. For example, Pratt et al. [42] found that lower socioeconomic populations and ethnic minorities were disproportionately exposed to traffic and air pollution and faced a higher risk of adverse health outcomes, and Neidell et al. [43] makes their conclusion from the research results that air pollution is a potential mechanism by which socio-economic status affects children's health.

2.4. Comments

The current studies provide some references for us to explore the relationship of new-type urbanization with environmental pollution and public health, but there are some issues to address: (i) Scholars have not yet reached a consensus on the mechanisms by which urbanization imposes impacts on environmental pollution and public health; (ii) Existing studies have mainly analyzed the impact of urbanization or its consequent air pollution on public health in a region, but the spillover effects in its surrounding areas have been less studied in that environmental pollution has a strong spatial spillover effect [44]. At the same time, with the advancement of the economy, interconnections among regions in various aspects, such as economics and healthcare, are becoming increasingly intertwined, particularly among cities that are geographically closer. Neglecting the potential impacts of spatial dependencies between these cities may result in significant biases or incorrect validation of model estimations [45]; (iii) The majority of the literature only examines the respective relationship of urbanization with environmental pollution and public health, but rarely investigates them in a comprehensive way and importantly, less research has been conducted to analyze the mediating role of air pollution in the impact of urbanization on public health; (iv) In the majority of the previous studies, urbanization is narrowly confined to the level of population urbanization, which does not reflect the level of socio-economic development in a surveyed region.

In this case, we attempt to address the questions from the following five aspects: (i) We will construct a novel urbanization index to comprehensively measure the level of urbanization in four dimensions: demographic urbanization, economic urbanization, social urbanization and spatial urbanization; (ii) Unlike previous studies that mainly analyzed the local impact of urbanization and environmental pollution on public health, we will introduce a spatial weight matrix to construct a spatial Durbin econometric to explore the impact of new-type urbanization and environmental pollution on public health locally as well as adjacent areas in order to fully qualify the examination of spatial relevance. (iii) For the sake of attaching importance to regional heterogeneity, which was neglected by previous researchers, we will explore the differences in the effects of the two core explanatory variables of new-type urbanization and environmental pollution on public health in the three sample regions of eastern, central and western China, with a view to providing a new direction of development and path options for each region and taking into account its own geographical environment, economic development characteristics and comparative advantages; (iv) Based on the mediating effects testing, we will further investigate the intrinsic mechanism of new-type urbanization on public health using environmental pollution as a mediating variable, so that the findings of the study can have richer theoretical connotations and practical significance; (v) Finally, we will employ an optional spatial weight matrix to test the robustness of the findings.

3. Study Design

Based on the above theoretical analysis, we propose the following conceptual relationships, depicted in Figure 1. The figure illustrates the main conceptual relationships between new-type urbanization, environmental pollution and public health.

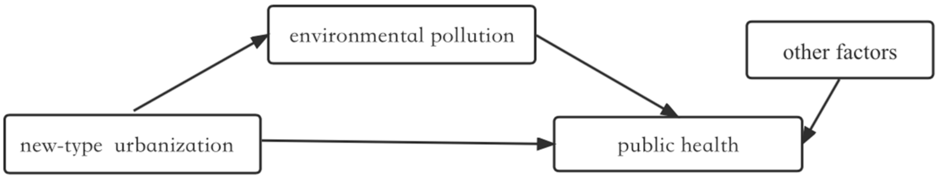

Figure 1. Conceptual relationship between new-type urbanization, environmental pollution and public health.

3.1. Variable Selection and Data Description

3.1.1. Dependent Variables

Level of public health (HL): In most international empirical studies, indicators such as infant mortality, population mortality, under-five mortality and maternal mortality are generally used to measure the health status of the population. Sen et al. [46] strongly advocated that the mortality rate is one of the most crucial indicators for assessing the quality of life and a central development goal. Mortality rates can be employed to evaluate health disparities among various regions, countries or populations, aiding in health policy formulation and resource allocation. Their impact on public health and the economy in urban areas is substantial. Given the availability of data for the indicators, we used population mortality rates to represent the health status of the population in each region, drawing on the study by Maisonet et al. [47].

3.1.2. Main Independent Variables

Environmental pollution level (lnEPI): In China, environmental pollution is primarily attributed to industrial pollution [48]. Environmental pollution encompasses various forms, with water, soil and air pollution having the most pronounced impact on human life. Local governments in China primarily report three major pollutants (industrial wastewater, industrial emissions, industrial solid waste) to comprehensively reflect the state of environmental pollution. Consequently, industrial waste (wastewater, SO_2, solid waste) is often used as a proxy for environmental pollution [49]. Wastewater is becoming a significant factor affecting freshwater quality and human health [50]. Wastewater is defined as water used by households, industries and commercial establishments that, unless treated, no longer serves any useful purpose and may contain contaminants [51]. It comprises water from household sinks, washing machines, kitchen appliances, and toilet flushes containing a mixture of nutrients and chemicals. Industrial contributions include nutrients such as carbon, nitrogen and phosphorus, as well as pesticides and chemicals specific to particular industries. Unless properly treated, these nutrients and chemicals may enter natural water systems, posing risks to the environment and human health [52].

This paper, therefore, incorporates per capita wastewater discharge, which includes per capita industrial wastewater discharge and per capita urban wastewater discharge. Due to reliance on coal for power generation, China has become the world's largest emitter of sulfur dioxide (SO_2). SO_2 combines with moisture in the atmosphere to form sulfuric acid (H_2SO_4), a major component of acid rain. Acid rain damages various organisms and environmental structures. In China, atmospheric sulfur dioxide emissions are a significant contributor to PM2.5 particulate matter suspended in the air [53]. The World Health Organization (WHO) [54] estimated that 30% of China's land area is significantly affected by acid rain. Tianbao et al. [55] pointed out that China is one of the countries heavily affected by acid rain pollution worldwide. Acid rain poses numerous threats to the environment, impacts people's quality of life, and even endangers human health. Due to China's sulfur dioxide emissions, acid rain in Japan and South Korea has been on the rise [53]. Therefore, this paper employs per capita sulfur dioxide emissions as an indicator of air pollution.

Compared to other environmental factors, issues related to atmospheric and water environments are both spillover and exogenous problems, which help mitigate endogeneity issues in this paper. Furthermore, per capita total particulate emissions, per capita total sulfur dioxide emissions, and per capita total wastewater emissions (Mass of smoke & dust emissions per capita) are closely related to economic activities within the urbanization process, such as industrial production, energy consumption, and transportation, and are major pollutants affecting public health. Hence, these three indicators are considered the primary metrics for evaluating environmental quality.

New-type Urbanization Index (NUI): Based on previous studies [56–58], we constructed an indicator system for new-type urbanization measurements with four dimensions: demographic urbanization, economic urbanization, social urbanization and spatial urbanization, from which the degree of new-type urbanization was evaluated. In our study, the two indicators of population urbanization rate and urban population density were used to measure population urbanization. Among these, high urban population density can lead to challenges such as traffic congestion, environmental issues, and housing shortages. Rainald Borck has also observed that higher population density is associated with deteriorating urban air quality [59], which negatively impacts both the sustainable development of cities and the quality of life for residents. GDP per capita and disposable income per urban resident to measure economic urbanization, the four indicators of road passenger traffic per 10 million people, health technicians per 10,000 persons, people with higher education per 10,000 persons and Engel's coefficient of urban residents to measure social urbanization, where the last indicator is derived from the proportion of urban residents' expenditure on food to total expenditure, typically, a lower Engel coefficient indicates a smaller proportion of household expenditures spent on food, which may suggest that urban residents have a relatively higher economic levels and a better quality of life. This is because they can afford more non-food expenditures, such as housing, education and entertainment [60]. One of the goals of new-type urbanization is often to improve the living standards of urban residents, promoting their economic growth and development. Therefore, from this perspective, an increase in the Engel coefficient may have a negative impact on new-type urbanization, as it reflects a decline in the economic status of urban residents. Finally, the three indicators of built-up area, road area per capita and park area per capita were used to measure spatial urbanization. As the new-type urbanization evaluation system involved multiple dimensions with many indicators, the new-type urbanization index values were calculated from the weighted indicators. As this is an objective and common method for determining the weights of indicators [61], the entropy method was used to calculate the new-type urbanization index values and determine the weights of each indicator. The meaning and weightage of each indicator are shown in Table 1.

Table 1. New-type urbanization level indicator system and its weight.

Second-Grade Indicators	Three-Grade Indicators	Weight	Effect
Population urbanization	Urban population as a proportion of total regional population (%)	0.0465	Positive
	Urban population density (persons/km^2)	0.0301	Negative
Economic urbanization	GDP per capita (Yuan)	0.0716	Positive
	Disposable income per urban resident (yuan/person)	0.0660	Positive
Social urbanization	Road passenger traffic per 10 million people	0.2623	Positive
	Number of health technicians per 10,000 people	0.0628	Positive
	Number of students in higher education per 10,000 population	0.1812	Positive
	Engel's coefficient for urban residents	0.0131	Negative
Spatial urbanization	Green space per capita (m^2/person)	0.0574	Positive
	Road area owned per capita (m^2/person)	0.0359	Positive
	Urban built-up land area (km^2)	0.2013	Positive

Note: Engel's coefficient for urban residents = urban residents' food expenditure/total expenditure × 100%.

3.1.3. Control Variables

Level of population aging (PPA): In our study, PPA was used as a control variable in that it has important implications for public health [62] On one hand, the increasing aging of the population in China significantly impacts its economic growth, fiscal spending, and household production. On the other hand, it places a substantial burden on regional healthcare services, particularly in areas with a high proportion of elderly residents. This, in turn, influences the utilization of healthcare services by other demographic groups, ultimately creating a ripple effect on public health levels. Based on China's current retirement age, the level of population aging was measured using the proportion of the population aged 65 years and over to the total population of the area.

Share of health expenditure (HES): HES was also used as a control variable in our study for the reason that the level of health expenditure represents the extent to which the government values and invests in health services. The share of health expenditure in local fiscal expenditure was calculated to measure the intensity of health expenditures in a region.

Proportion of the population employed in the tertiary sector (RTG): In China, the population employed in the tertiary industry is mainly engaged in circulation and service industry, and proportion of them is generally considered as an important factor influencing the health care sector as well as the level of public health in a region [32], RTG was employed in the study as the third control variable for the reason that the employees in the tertiary sector in China are at relatively higher risk of health problems because of the long and intense working hours and the physical and mental health effects of excessive labor as well as more frequent exposures to disease inducing surroundings especially infectious diseases.

3.1.4. Data Description

The data used in this study were acquired from public sources. The data for the variables were obtained from the China Statistical Yearbook (2010–2020) and the China City Statistical Yearbook (2011–2020), China Population Census Data (2000–2020), 1% Population Sample Survey Data by provincial administrative units (2005 and 2015), published by the National Bureau of Statistics (http://www.stats.gov.cn/tjsj/ndsj/, accessed on 3 July 2022) and the Health and Health Commission of the People's Republic of China (http://www.nhc.gov.cn, accessed on 4 July 2022), China Health Statistics Yearbook (2011–2020). The samples were taken from sources dating from 2011 to 2020, totally targeting 2750 observation points in 275 prefecture-level cities in China. The geographic information-based data were obtained from the National Mapping and Geographic Information Bureau's standard map service website (http://bzdt.ch.mnr.gov.cn, accessed on 11 June 2022). The descriptive statistics of the variables were conducted as shown in Table 2.

Table 2. Descriptive statistics of the variables.

Variable	Meaning	N	Max	Min	Mean	Std.Dev.
HL	Level of public health	2750	18.1200	0.9000	6.2525	1.6833
lnEPL	Environmental pollution level	2750	14.3790	4.5816	9.5751	1.0917
NUI	New-type urbanization index	2750	0.8420	0.0259	0.1651	0.1041
$(NUI)^2$	New-type urbanization index square	2750	0.7090	0.0007	0.3810	0.5918
HES	Share of health expenditure	2750	29.5725	0.0037	9.1868	2.5793
PPA	Level of population aging	2750	22.6700	1.9310	11.8001	2.9591
RTG	Proportion employed in the tertiary sector	2750	94.8200	15.3900	53.8976	13.6050

3.2. Construction of the Spatial Econometric Model

3.2.1. Settings of the Spatial Econometric Model

Since new-type urbanization, environmental pollution and public health are highly inter-correlated in space, a spatial econometric mode [63] is proposed in this study to ensure their spatial spillover effects against bias while avoiding endogeneity of the variables by introducing the Spatial Durbin Model (SDM), which favorably incorporates the Spatial Lag Model (SLM) and Spatial Error Models (SEM): The former explores whether the dependent variables are spatially correlated, while the latter explores whether omitted variables or random error terms in the model produce spatial spillover effects. SDM is more commonly used for econometric modeling with the following equation [64]:

$$Y = \rho WY + X\beta + WX\theta + \mu + \gamma + \varepsilon \tag{1}$$

where Y and X are the explanatory variables, β the coefficient of the explanatory variable, μ the time fixed, γ the individual fixed and ε the residual term; W is the spatial weight matrix reflecting the relationship between regions, WY the spatial lagged term of the explanatory variable and ρ the spatial regression coefficient of the explanatory variable; WX is the spatial lagged term of the independent variable and θ the spatial regression coefficient of the independent variable. When θ = 0, SDM degenerates to SLM; when ρ = 0, SDM degenerates to SEM.

Considering that there may be a non-linear relationship between the level of new-type urbanization and public health, we included a quadratic term for the level of new-type urbanization in the model. In order to reduce the effect of heteroskedasticity, furthermore, we used the logarithm of a variable that was not of the ratio type—the environmental pollution index—to reduce the effects of heteroscedasticity and thus obtained the specific form of the model by means of the following equation:

$$\begin{aligned} HL_{it} = \alpha + \rho WHL_{it} + \beta_1 lnEPI_{it} + \beta_2 NUI_{it} + \beta_3 (NUI)^2_{it} + \beta_4 HES_{it} + \beta_5 PPA_{it} + \beta_6 RTG_{it} + W\theta_1 lnEPI_{it} \\ + W\theta_2 NUI_{it} + W\theta_3 (NUI)^2_{it} + W\theta_4 HES_{it} + W\theta_5 PPA_{it} + W\theta_6 RTG_{it} + \mu_i + \gamma_t + \varepsilon_{it} \end{aligned} \tag{2}$$

where $\varepsilon_{it} \sim N(0, \sigma^2 I_n)$; i = 1, 2, 3, . . ., 275; t = years ranging between 2011–2020. To test the feasibility of the model, we first used exploratory spatial data analysis methods (i.e., spatial correlation tests) to determine the existence of spatial effects of the variables, followed by employing LM (Lagrange multiplier) tests and robust (LM) tests to determine the existence of spatial error terms and spatial lagged terms according to Anselin [65]. If both were present, the SDM was used for subsequent regression analysis. After that, the Wald test (Wald) and the likelihood ratio test (LR) were used to examine whether the SDM model could be degraded to a SLM model or SEM model and ultimately to determine the regression form of the model. Since β_2 and β_3 represent the primary and secondary coefficients of the NUI, respectively, the critical value of NUI can be mathematically expressed as $\text{NUI} = -\frac{\beta_2}{2\beta_3}$. Here, the critical value is expressed as the threshold at which public health changes from improving to deteriorating, or vice versa, as the level of urbanization changes.

3.2.2. Spatial Weight Matrix [66]

In this paper, the geographic inverse distance matrix [67] (W_1) was used as the normalized spatial weight matrix for spatial regression analysis, with the equation as follows:

$$W_{1,ij} = \begin{cases} 1/d^2, & i \neq j \\ 0, & i = j \end{cases} \tag{3}$$

The matrix was obtained by taking the coordinates of the two cities in order to calculate the spherical distance D_{ij} between the two cities and then calculating the reciprocal of the square of D_{ij} in order to observe the proximity of the two cities and investigate the accessibility of transportation. In addition, we chose the economic-geographic nested weight matrix [67] (W_2) for robustness testing in this study to enhance the robustness of the findings to exclude the chance of chance arising from the use of a single spatial matrix, In the economic-geographic nested weight matrix. Both economic and geographical factors are involved, and its elements are determined by the ratio of GDP per capita ($rgdp_i$) of region I to GDP per capita ($rgdp_{all}$) of all regions and the linear distance D_{ij} between is the two regions. W_2 can be expressed as follows:

$$W_{2,ij} = \frac{1}{D_{ij}} * \frac{rgdp_i}{rgdp_{all}} \tag{4}$$

3.2.3. Spatial Correlation Test

To test the spatial correlation, we calculated the Moran's Index of the model using the method by Getis [68]. More specifically, the global Moran's Index was calculated by means of a spatial weight matrix based on W_1, with the equation as follows:

$$\text{Moran's } I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}\left(Y_i-\overline{Y}\right)\left(Y_j-\overline{Y}\right)}{\left(\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}\right)\sum_{i=1}^{n}\left(Y_i-\overline{Y}\right)^2} \tag{5}$$

where Y_i denotes the observation of area i, n the number of areas and W_{ij} the spatial weight matrix based on geographical inverse distance. The global Moran's Index represents the overall spatial correlation, and its assessment may ignore atypical characteristics of local areas. This means that in the global Moran's Index, certain local areas' distinctive patterns or anomalies may be overshadowed by the overall trend because it primarily focuses on global spatial correlation. To test the local spatial correlation, we plotted the Moran's Index scatter plot by calculating the local Moran's Index [69]. The local Moran's Index is calculated as:

$$\text{Moran's } I_{\text{i}} = \frac{n\sum_{j=1}^{n}W_{ij}\left(Y_i-\overline{Y}\right)\left(Y_j-\overline{Y}\right)}{\sum_{i=1}^{n}\left(Y_i-\overline{Y}\right)^2} \tag{6}$$

3.2.4. Mediating Effect Model

The mediating effect refers to the indirect effect of independent variables on dependent variables by influencing intermediary variables. The effect of the independent variable (X) on dependent variable (Y) was modeled through mediating variable (M). The intermediate effects test serves to provide additional insight into how the independent variable affects the dependent variable. We used the mediating effects test procedure proposed by Wen et al. [70]. This test procedure is largely based on the three-step approach proposed by Baron and Kenney et al. [71], with the following test equations:

$$Y_{it} = cX_{it} + e_{i1t1} \tag{7}$$

$$M_{it} = aX_{it} + e_{i2t2} \tag{8}$$

$$Y_{it} = bM_{it} + dX_{it} + e_{i3t3} \tag{9}$$

First, the regression coefficient of the test Equation (7) is tested and if c is significant, the condition for the existence of intermediate effects is initially established. Next, the regression coefficient a of Equation (8) and the regression coefficient b of Equation (9) are tested and if both are significant, the indirect effect is proven to be significant. Finally, the regression coefficient d of Equation (9) is tested. If the value of d is significant, it indicates a significant direct effect, i.e., there is a partial mediation effect, and if the value of d is not significant, there is a full mediation effect.

As new-type urbanization may potentially impact public health through its influence on environmental pollution, we introduced a mediation effect model into a spatial econometric model to further examine the relationship among the three variables. In this study, public health is the dependent variable Y, environmental pollution is the mediating variable M, and urbanization is the independent variable X. The specific model is as follows:

$$\begin{aligned} lnEPI_{it} = {} & \alpha_2 + \rho_2 WlnEPI_{it} + \vartheta_1 NUI_{it} + \vartheta_2 (NUI)^2_{it} + \vartheta_3 HES_{it} + \vartheta_4 PPA_{it} \\ & + \beta_5 RTG_{it} + W\lambda_1 NUI_{it} + W\lambda_2 (NUI)^2_{it} + W\lambda_3 HES_{it} \\ & + W\lambda_4 PPA_{it} + W\lambda_5 RTG_{it} + \mu_i + \gamma_t + \varepsilon_{it} \end{aligned} \tag{10}$$

$$\begin{aligned} HL_{it} = \alpha_1 + \rho_1 WHL_{it} + \varphi_1 NUI_{it} + \varphi_2 (NUI)^2_{it} + \varphi_3 HES_{it} + \varphi_4 PPA_{it} \\ + \varphi_5 RTG_{it} + W\gamma_1 NUI_{it} + W\gamma_2 (NUI)^2_{it} + W\gamma_3 HES_{it} \\ + W\gamma_4 PPA_{it} + W\gamma_5 RTG_{it} + \mu_i + \gamma_t + \varepsilon_{it} \end{aligned} \quad (11)$$

Equations (2), (10) and (11) are composed to make the complete mediating variable model, where Equation (2) corresponds to Equation (9) in the mediating variable model, and Equations (10) and (11) to Equations (7) and (8) in the mediating variable model.

4. Empirical Results

4.1. Spatial Correlation Tests for Public Health

We used Stata15.1 software to determine the spatial spillover effects of public health levels by conducting global autocorrelation tests and local autocorrelation tests for 275 prefecture-level cities from 2011 to 2020. The global Moran's Index test showed that the global Moran index for 2010–2020 was greater than 0 and all passed the test at the 5% level of significance, indicating a significant spatial dependence of public health (See Table 3).

Table 3. Moran's Index of public health levels.

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Moran's I	0.0511	0.0595	0.0724	0.0502	0.0842	0.0449	0.1070	0.0675	0.0469	0.0940
Z	7.3618	8.5032	10.222	7.1721	11.7920	6.4258	14.8630	9.4217	6.6932	13.1800
p	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010

Since the global correlation test can only describe the spatial variables as a whole, local atypical features are likely to be overlooked. Thus, in order to further explore the characteristics of the distribution of public health levels in the local areas, further local correlation tests are needed. In 2011, the Chinese government first introduced "new-type urbanization" as a vital means of boosting domestic demand. In 2014, China released the "National New-Type Urbanization Plan (2014–2020)", marking a significant shift in urbanization. By 2017, the middle year of the 2014–2020 period, there had been a continuous and steady improvement in the health levels of Chinese residents from 2011 to 2020 [72], thus we only showed our local Moran's I scatter plots under the W_1 matrix using the data from representative years 2011, 2014, 2017 and 2020, as shown in Figure 2. Quadrant 1 was the H-H catchment area, representing the high public health level area adjacent to an area with high quality of public health. Quadrant 3 was the L-L catchment area, representing the two adjacent areas of lower public health, and quadrants 2 and 4 were the L-H and H-L quadrants, respectively. Meanwhile, it can be observed that in 2017, both the global and local Moran's indices were higher than in other years. Furthermore, the fact that the vast majority of cities had public health levels in the first and third quadrants further suggests that public health in China is characterized by a high degree of spatial clustering across regions, which requires attention to the use of spatial correlation of public health when exploring the relationship between new-type urbanization, environmental pollution and public health, or else the estimation can be biased. Therefore, it is reasonable to introduce a spatial econometric model to investigate the influence mechanism between the three factors.

In order to visualize the distribution of public health levels by region in China, we selected public health data published by the prefecture-level cities in China in 2011, 2014, 2017 and 2020 as sample data and visualized them by drawing maps using ArcGIS 10.2 software. In order to show the differences between regions more clearly, we used an equivalence method for drawing the map to classify the public health level into five levels: high (0 to 4.2600), slightly high (4.2600 to 7.6200), medium (7.6200 to 10.9800), slightly low (10.9800 to 14.3400) and low (14.3400 to 17.7000). As can be seen in Figure 3, there was a clear clustering of public health levels. The cities with low public health levels were clustered in similar areas, particularly in the northeast. There was also a clustering of high public health areas and similar areas, particularly in the central-eastern regions.

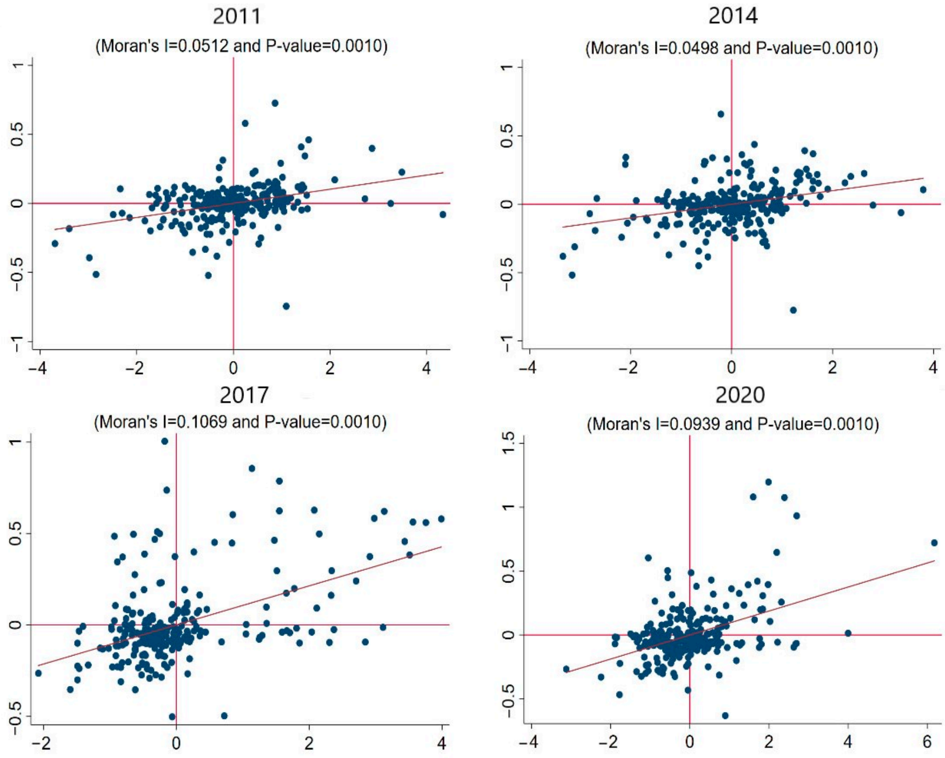

Figure 2. Moran scatterplot of public health levels in China, 2011, 2014, 2017 and 2020.

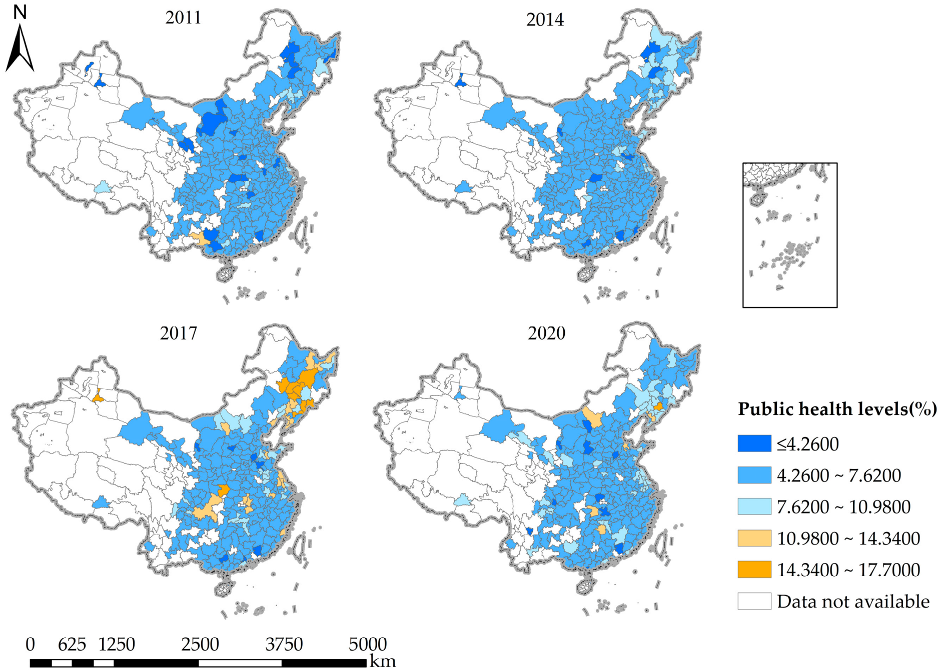

Figure 3. Interurban spatial distribution of public health levels in 2011, 2014, 2017 and 2020.

4.2. Spatial Model Regression Results

Before conducting spatial econometric analysis, we identified the spatial correlation and spatial lag using the LM test and Robust LM test. As shown in Table 4, LM (error) and

Robust LM (error) statistical values were 851.0242 and 832.2433, respectively, passing the 5% significance test, indicating the existence of spatial error items. LM (lag) statistical value and Robust LM (lag) statistical value were 38.2590 and 8.1275, respectively, passing the 5% aboriginality test as well, indicating that the model had spatial lag. In general, a more generalized spatial Durbin model should be selected. On this basis, the Wald test (Wald) and likelihood ratio test (LR) were further used to examine whether this SDM could be degraded to a SLM or a SEM. As shown in Table 4, the LR-lag and LR-error statistics were 19.7271 and 35.3704, respectively, and the Wald-lag and Wald-error statistics were 18.0410 and 16.9020, respectively, all passing the 5% significance test, so the original hypothesis of SDM degenerating into SLM or SEM was rejected. Therefore, we turned to use the SDM for the subsequent spatial econometric analysis. In addition, a choice was made as to whether fixed or random effects should be used in the model. The Hausman test statistic rejected the original hypothesis at a 5% confidence level (as shown in Table 4), indicating that the random effects model should be rejected and therefore fixed effects are more appropriate for the model setting. The specific regression results are shown in Table 5.

Table 4. LM, LR, Wald and Hausman test results.

Test	Statistical Quantities	*p*-Value
Lagrange multiplier (error)	851.0242	0.0000
Robust Lagrange multiplier (error)	832.2433	0.0000
Lagrange multiplier (lag)	38.2590	0.0000
Robust Lagrange multiplier (lag)	8.1275	0.0421
Wald spatial lag	18.0410	0.0025
Wald spatial error	16.9020	0.0041
LR spatial lag	19.7271	0.0027
LR spatial error	35.3704	0.0009
Hausman	63.5865	0.0000

Table 5. Empirical results.

	Equation (2)	Equation (11)	Equation (10)
	HL	HL	lnEPL
lnEPL	6.3704 *** (19.96)		
NUI	14.5620 *** (3.97)	16.3927 *** (3.86)	0.6281 ** (2.82)
$(NUI)^2$	−17.8938 ** (−3.47)	−14.7690 * (−2.13)	−0.5315 * (−2.27)
W*lnEPL	2.5731 * (2.27)		
W*NUI	19.2527 * (2.01)	17.8629 * (1.67)	0.8924 (1.07)
$W^*(NUI)^2$	−29.0932 * (−2.19)	−21.6059 * (−1.73)	−1.1647 (−1.16)
HES	0.0121 (0.28)	−0.0228 (−0.94)	−0.0121 * (−2.21)
PPA	0.5937 *** (9.74)	0.8479 *** (7.96)	0.0415 ** (2.79)
RTG	0.0381 ** (2.59)	0.0134 * (1.69)	−0.0054 * (−1.63)
R^2	0.6834	0.4578	0.4162
N	2750	2750	2750

Note: *, **, *** denote significant at the 10%, 5% and 1% levels respectively, with Z values in brackets.

According to Equation (2) in Table 5, environmental pollution had a significant negative effect on public health after including environmental pollution as a mediating variable. The coefficients of lnEPL and W*lnEPL were 6.3704 and 2.5731, ($p < 0.01$; $p < 0.1$), indicating that environmental pollution, in both local and spatial spillover effects, reduced the level of health. The new-type urbanization had a significant effect on public health, with a 'positive U-shaped' relationship between them. The coefficients of NUI and $(NUI)^2$ in Equation (2) were 14.5620 and −17.8938, respectively, both passing the significance test ($p < 0.05$). Therefore, in terms of local effects, the new-type urbanization had a 'positive U-shaped' effect on the improvement of public health, with an inflection point of 0.4069, labeled as T1, i.e., T1 = 0.4069. Beyond this inflection point, new-type urbanization began to have a positive impact on the level of health. The coefficients of W*NUI and $W^*(NUI)^2$ were

19.2527 and −29.0973, respectively, and both were found to be significant ($p < 0.1$). This result suggests that the spatial spillover effect of new-type urbanization on public health is also 'positively U-shaped' so that it first inhibits and then promotes the improvement of public health. This is consistent with the findings of Haitao Wu [6]. The coefficients of NUI and $(NUI]^2$ in Equation (11) were 16.3927 and −14.7690, respectively, and the coefficients of W*NUI and $W^*(NUI)^2$ were 17.8629 and −21.6059, respectively, both of which were significant ($p < 0.1$). This result shows that the local and spatial spillover effects between new-type urbanization and public health had a positive U-shaped relationship, presenting little mediating effect of environmental pollution, which is consistent with the results of Equation (2). According to the procedure for testing mediating effects, we also needed to test the effect of new-type urbanization on environmental pollution in order to verify whether the variable of environmental pollution mediates the mechanism of the effect of new-type urbanization on the level of public health. As seen in Equation (10), the regression coefficients of NUI and $(NUI)^2$ were 0.6281 and −0.5315, respectively, both of which were significant at 95% and 90%, indicating that new-type urbanization had a significant local impact on environmental pollution by first promoting and then inhibiting it. This aligns with the research results of Shuwang Yang et al. [73]. In other words, the two had an 'inverted U-shaped' relationship, with an inflection point of 0.5908, which was labeled as T2. Beyond this inflection point, new urbanization began to have a negative effect on environmental pollution. Therefore, we can consider environmental pollution as a mediating variable for the impact of new-type urbanization on public health, presenting partial mediation. In terms of the regression results for the control variables, the coefficients for both the variables of population aging and the share of tertiary employment in Equations (2) and (11) were both significantly negative, indicating that both had a significant negative impact on public health. This corresponds with the earlier research findings by scholars [74,75]. However, the controlled variable of the proportion of healthcare expenditure did not show a significant impact on the level of health.

In order to more visually demonstrate the level of new-type urbanization across the inflection point in each region of China, we plotted Figure 4 using the inflection points T1 = 0.4069 and T2 = 0.5908 as the stratification criteria. The gray color in the figure represents the cities that had not yet crossed inflection point T1, and the color red represents the cities that had crossed inflection point T1 but not T2. In other words, the cities in red had yet to curb environmental pollution, although their new-type urbanization levels contributed positively to local public health to a broad extent. The color blue marked the cities that had crossed T2, indicating that the new level of urbanization in these cities could not only help to curb the issue of environmental pollution but also contribute to the improvement of local public health. From Figure 4, it becomes apparent that a relatively small proportion of Chinese cities passed inflection point T1, and almost all of them were located in the eastern region of China with rapid economic development. By 2020, for example, only eight cities had crossed inflection point T1, including Beijing, Shanghai, Nanjing, Wuhan, Guangzhou, Dongguan, Chongqing and Guiyang, with only the city of Gaungzhou crossing the T2 inflection point.

4.3. Robustness Tests

To ensure the reliability of these results, we conducted robustness tests by replacing the spatial weight matrix. Table 6 shows the empirical results we obtained by replacing the geographical inverse distance matrix (W_1) using the economic geographical nested weight matrix (W_2). By comparing the empirical results in Table 6 with those in Table 5, we found that the results in Equations (2), (10) and (11) were largely consistent, and therefore, our findings were robust and reliable.

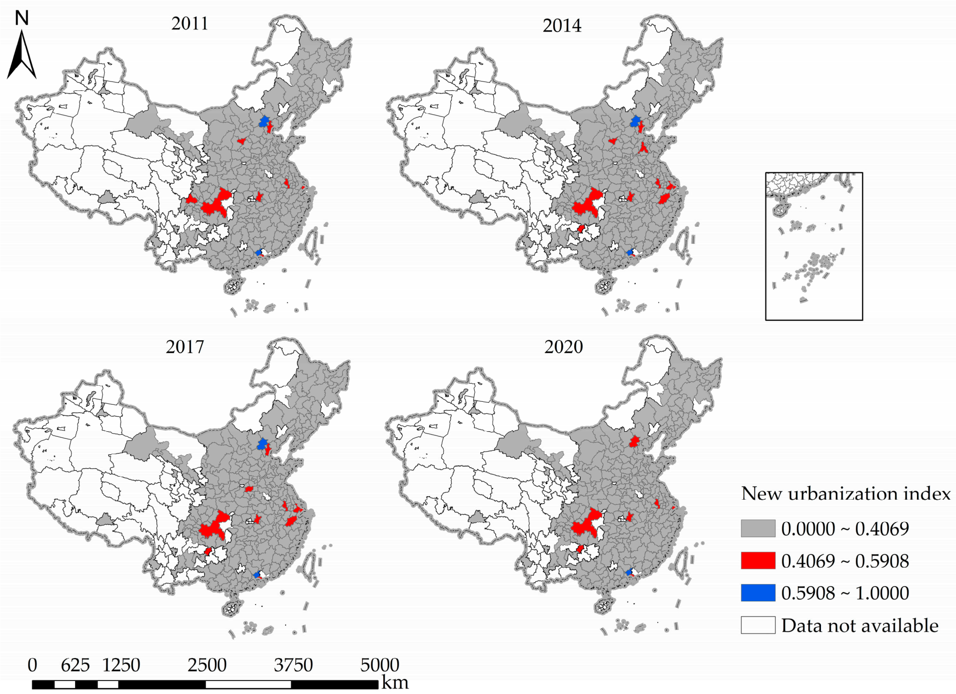

Figure 4. Distributions of cities having crossed inflection points.

Table 6. Empirical Results of Robustness Tests.

	Equation (2)	**Equation (11)**	**Equation (10)**
	HL	**HL**	**lnEPL**
lnEPL	7.5901 *** (24.27)		
NUI	15.4083 *** (5.84)	18.4741 *** (5.76)	0.8751 *** (4.02)
$(NUI)^2$	−21.6843 *** (−4.98)	−16.6784 ** (−2.79)	−0.8218 ** (−2.98)
W*lnEPL	11.3572 *** (3.97)		
W*NUI	87.4762 ** (3.29)	18.3662 * (1.71)	0.9221 (1.35)
$W^*(NUI)^2$	−121.1238 ** (−2.91)	−24.3286 * (−1.81)	−1.2133 (−1.56)
HES	0.0131 (0.86)	−0.0247 (−0.99)	−0.0064 * (−2.31)
PPA	0.3927 *** (7.49)	0.6716 ** (7.67)	0.0562 ** (2.85)
RTG	0.0731 *** (3.97)	0.0267 (0.81)	−0.0043 * (−1.71)
R2	0.7186	0.5327	0.4367
N	2750	2750	2750

Note: *, **, *** denote significant at the 10%, 5% and 1% levels respectively, with Z values in brackets.

4.4. Sub-Regional Spatial Panel Regression Results

The above results suggest that there is a strong correlation between the new-type urbanization, environmental pollution and public health levels at the national spatial level; meanwhile, at the local spatial level, there may exist typical situations that are different or even completely contradictory to the national spatial level. China has a vast land area, and there are substantial variations in economic development, industrial structure, resource endowments, and national policies across different regions. For example, the eastern regions of China have higher levels of openness and technological advancement, while the central and western regions benefit from certain national incentives and policies [76]. Hence, the impact of new-type urbanization may vary across different regions, making the study of heterogeneity in the effects of new-type urbanization of practical significance. Therefore, we further analyzed the relationships between the three variables in terms of regional heterogeneity. First, by considering the economic development level and geographical location as a whole, we divided China's prefecture-level cities into three broad regions: east, central and west [77], and visualized them by drawing a map in different colors, as seen in Figure 5. We then proceeded with the empirical analysis of the three regions using the SDM method based on the geographic inverse distance matrix (W_1), obtaining the empirical results presented in Table 7.

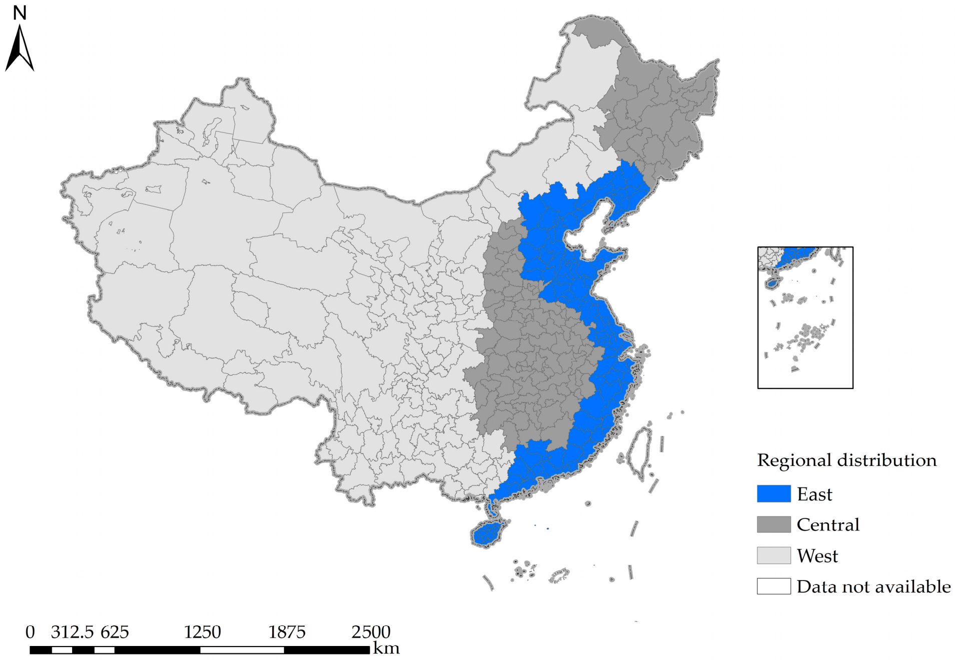

Figure 5. Regional distributions of the eastern, central and western regions.

Table 7. Empirical results on the level of public health in the regions.

	East	**Central**	**West**
lnEPI	5.9271 *** (23.78)	6.1232 *** (19.22)	6.9276 *** (20.54)
NUI	−11.7980 * (−2.27)	−36.2539 * (−2.47)	23.2197 ** (3.14)
(NUI)^2	12.5451 * (2.12)	45.2974 * (2.42)	−34.2395 * (−2.11)
W*lnEPI	2.9342 ** (2.86)	2.3751 (1.32)	2.8691(1.18)
W*NUI	−18.8672 ** (−2.83)	35.1289 (1.25)	59.3292 *** (3.68)
W*(NUI)^2	24.8591 *** (3.69)	−87.2195 (−1.55)	−124.5124 ** (−3.10)
HES	−0.2815 *** (−5.38)	−0.0251 (−0.62)	−0.0582 (0.84)
PPA	0.0613 * (2.11)	1.8521 *** (8.32)	3.2539 *** (6.21)
PTG	0.0892 ** (3.24)	0.0401 *** (3.51)	0.0563 (0.98)
R2	0.7641	0.6727	0.6209
N	980	1000	770

Note: *, **, *** denote significant at the 10%, 5% and 1% levels respectively, with Z values in brackets.

As shown in Table 7, the empirical results for the western region were generally consistent with those for China as a whole when the sample was sub-regionally split. Surprisingly, however, the coefficient estimates of the core variables for the eastern and central regions showed variability with the empirical results for China as a whole. In the eastern region, the regression coefficients of NUI and (NUI)^2 were −11.7980 and 12.5451, respectively, and the regression coefficients of W*NUI and W*(NUI)^2 were −18.8672 and 24.8591, respectively, with both being significant at the 5% level, indicating that new-type urbanization and public health had an 'inverted U-shaped' relationship in terms of both local effects and spatial spillover effects. In the central region, the NUI and (NUI)^2 were −36.2539 and 45.2974, respectively, both being significant at the 5% level, but the W*NUI and W*(NUI)^2 did not pass the significance test (p-value greater than 0.05), indicating that there was a local 'inverted U-shaped' relationship between the new-type urbanization and public health, but no spatial spillover effect. This result is similar to the findings of Chang Zhao et al. [78].

5. Discussion

5.1. Main Achievements

With the gradual increase in public awareness of public health and environmental preservation, the issue of environmental pollution and the health of the population are attracting increased attention in society. Despite that it propels socio-economic development [79], urbanization can be detrimental to the environmental quality of cities as well as to public health. In this case, how to balance urbanization with environmental quality and public health has become a prevalent topic of discussion in the process of human survival and development. Based on previous studies, this paper has investigated the impact mechanisms of new-type urbanization and environmental pollution on public health from both local and spatial perspectives using statistical methods and analyzing the panel data of 275 prefecture-level cities from 2011–2020 using the spatial Durbin model and the mediating effects model. Furthermore, we conducted a regional heterogeneity test for the three major regions, namely eastern, central and western China, with the aim of clarifying the relationship between new-type urbanization, environmental pollution and public health. The research results are as follows.

Firstly, new-type urbanization had a ‘positive U-shaped’ local effect and a spatial spillover effect on public health in terms of the effect of total variable at the national level in China, indicating that the new-type urbanization had an impact on public health in the local areas, as well as a radiating effect on public health in the surrounding areas. This empirical finding is attributed to the overall transformation of China’s urbanization development model (from expansion to quality improvement) [80]. In the first stage of urbanization, China mainly followed a scale- and spatially oriented urbanization path, which was accompanied by an increase in the scale of factors, but the benefits could not keep up with the rapid pace of urbanization, resulting in a shortage of public service provision and a high risk of environmental pollution, which in turn had a negative impact on public health. However, as urbanization is oriented along a more people-centered and environment-friendly path, the quality of urban development increases in terms of structural optimization and functional form within the cities. Additionally, ‘urban diseases’ related to environmental pollution, traffic congestion and social misgovernance might be taken care of as well in the course of time.

Secondly, the findings in our study pointed to an ‘inverted U-shaped’ local effect of new-type urbanization on environmental pollution. Specifically, the urbanization of the regions increased, while the local environment deteriorated. As a matter of fact, the urbanization of China took an expansionary scale in its early stage, when a large number of the agricultural population migrated to the cities and metropolitans along the coastal areas so that the pressures of production and living space brought about negative externalities of urban population agglomeration. In recent years, urbanization has transformed from a scale-oriented expansion to quality-oriented development so that the economy of scale effect has brought about population and industrial agglomeration [81], it paving a way to improve the environmental quality, which is verified from our findings in the study. Aside from its attribution to a deteriorating environment as a society advances from a low to a medium level of social economic form, based on the ecological modernization theory [82], urbanization in return gives birth to technological innovation and industrial transformation in the process of economic growth, eventually bringing about an improvement in the environmental quality as the society becomes advanced [83]. Additionally, in 2017, both the global and local Moran’s indices for public health levels were higher than in other years. This may be attributed to the policy implementation of the “13th Five-Year Plan for Deepening the Reform of the Medical and Health System” by the State Council in early 2017. Several Chinese cities began piloting the implementation of tiered diagnosis and treatment, family doctor contract services, and various coexisting medical payment methods, among other healthcare system reforms [84]. These reforms led to a more concentrated geographical distribution of residents’ health levels. Interestingly, our findings even discovered a significantly negative effect of the aging level as well as the employment proportion of the tertiary industries on local public health, which is consistent with the findings by Chang et al. [85]. Actually, the elderly populations and those employed in the tertiary industries are more vulnerable to the fallouts of urbanization, and they are desperately in need of high-quality health care [86], which encumbers the overall public health of a region. Simultaneously, we also found that the proportion of healthcare expenditure did not significantly affect residents' health levels. This might be because health levels are influenced by multiple factors, with healthcare expenditure being just one aspect; it may appear relatively insignificant compared to the impacts of urbanization and environmental pollution, among other factors [87]. Research indicates that even with ample healthcare expenditure, if healthcare service quality is low, medical resources are unevenly distributed, or regional economic development lags, the influence of healthcare expenditure on health levels may weaken [88]. Therefore, the proportion of healthcare expenditure itself may not necessarily reflect residents' health levels. At this point, urbanization is seen to affect public health in different ways, among which environmental pollution functions. This is verified by the results from the mediating effects test in our study, suggesting that urbanization and urbanization-induced urban environmental pollution can affect public health independently or synergistically, which is consistent with previous research findings [89]. Rapid and unplanned urban expansion in the context of urbanization endangers the environment by polluting soil, water and air. Consequently, soil, water and air pollution progressively undermine public health, inviting myriad diseases, including cancers of all types [90,91].

Thirdly, in terms of the spatial distribution of cities, the cities crossing the inflection point T1 accounted for a minority of China's cities, with almost all located in the eastern region where economic development has been faster. In response to this result, it is clear on the one hand that urbanization in most Chinese cities still negatively impacts the local environment and public health, so it remains challenging for China to continue increasing urbanization levels and minimize environmental changes (e.g., air pollution, water pollution, noise pollution, etc.) and public health risk factors (e.g., mental stress, overcrowding, social isolation, etc.) associated with urbanization. On the other hand, there is a synergistic relationship to some extent between the level of economic development of a region and the level of its urbanization, which is consistent with the findings obtained from World Bank data [79]. The eastern regions have attracted a large amount of foreign investment due to their location and history, and their economic development has been among the highest in all of China's regions, and in the process has led to the development of urbanization in the region. As such, utilizing the economic and urbanization development lessons from the eastern region to promote the development of the central and western regions is an issue that China needs to address now and in the future.

Fourthly, by a heterogeneity analysis using a sample of three regions, the impact of new-type urbanization and its consequent environmental pollution on public health was significantly different across the three regions, e.g., eastern, central and western China. Specifically, for west China as well as China as a whole, new-type urbanization had a 'positive U-shape' relationship with public health, with respect to both local effects and spatial spillover effects. In contrast to western and overall China, east China displayed a unique relationship between new-type urbanization and public health, characterized by an 'inverted U-shape' for both local and spatial effects. In the central region, an 'inverted U-shape' relationship with public health was observed only at the local level, not in terms of spatial effects. In our understanding, the regional heterogeneity across the regions is explainable as follows: For the first facet, east China grew as the main agglomeration of China's rural-urban floating population in the early stages of new-type urbanization because of China's initial policy of reforms and opening-up along the coastal areas, enabling a large population to access the economic benefits as well as health care; for the second, as stated in the health migration hypothesis, there is a self-selection effect, that is, the mobile population is generally in better physical condition, and their health status is selectively better than that of the general population in the place of emigration and the place of entry [92]. As a result, the influx of the large mobile population at the beginning of the new-type urbanization generally contributes to the improved health of population [93].

On one hand, the urbanization-induced regional ecological environment change in the relatively affluent eastern regions, encumbered by the pattern of relatively prominent 'industrialization-led, urbanization-lagged' development, posed serious health risks to the public health of the local population [94], such as the urban heat island effect leading to frequent local heatwaves, and the declining air quality in urban areas contributing to an increased incidence of respiratory diseases among residents. Meanwhile, the number of urban-rural migrants in the urban villages was most vulnerable to respiratory diseases and injuries because of the poor living conditions and inadequacy of quality health care. Unlike in Western countries, China's migrant population suffered from inequality in employment, housing, social welfare and educational opportunities because of restrictions posed by China's 'household registration' system [95], which makes them more vulnerable to health risks. Therefore, the process of urbanization can explain why it exerted a 'inverted U-shaped' effect on public health in east China because it promoted and then inhibited the development of public health. Secondly, China's regional integration strategy in recent years has paved the way for urban agglomeration, which has given rise to the three largest and most mature urban agglomerations in China (including Beijing-Tianjin-Hebei, the Yangtze River Delta and the Pearl River Delta) encompassing almost all the metropolises along coastal China. Such urban agglomerations bring about positive externalities such as the optimization of factor allocation, knowledge and technology spillover and information equipment sharing because of their strong economic agglomeration and closely interconnected geographic space, but as a typical compact economic behavior that focuses on development and ignores ecology, they are therefore prone to environmental pollution due to problems related to increased energy consumption and environmental degradation due to expansion of production capacity. In particular, the "pollution clusters" are prominent. For example, the pollution levels of the three major urban agglomerations are much higher than the national average, as published in the 2014 "China Cities 100 Forum". In general, there is a strong spatial linkage between the cities in east China, which explains the spatial spillover effects between the new-type urbanization and public health in the region by presenting the same 'inverted U-shaped' relationship as the local effects. Finally, the new-type urbanization also exerted an 'inverted U-shaped' local effect on public health in central China. We speculate that this phenomenon may be attributed to the central region's geographical position as an intermediary between the eastern and western regions. In recent years, due to resource and environmental constraints, as well as rising labor costs, the eastern region has been steadily transferring a significant portion of its traditional technology-driven manufacturing and labor-intensive industries to the central region as the deepening of China's economic regionalization. Given its role as a major industrial center, the central region bears a substantial burden on polluting industries. While the increasing levels of industrialization and urbanization in the central region initially bring certain health benefits to local residents, the relationship between industrialization and urbanization may become increasingly incongruent. This "emphasis on development at the expense of ecology" model leads to a series of ecological environment changes, ultimately resulting in a backlash against the improvement in public health. Consequently, the public health levels in the central region may exhibit an initial improvement, followed by deterioration as urbanization advances.

5.2. Sub-Regional Spatial Panel Regression Results

Most of the previous literature has used cross-sectional data to analyze the relationship between the independent and dependent variables of urbanization, environmental issues and public health, and a time series approach can be used to determine the causal relationship between these variables. This study uses panel data containing both time series and cross-sectional information to investigate the relationships between urbanization, environmental pollution and public health, trying to elaborate their relationships. However, there are still certain shortcomings to our current study. Firstly, our study has only generalized the new-type urbanization as a composite index and examined the relationship between this variable and other two, but it remains uninvestigated how its four dimensions (Population urbanization, Economic urbanization, Social urbanization, Spatial urbanization) affect the other two variables, which is certainly a worthy subject for further study. Secondly, although our research emphasizes that environmental pollution is an important mechanism, urbanization may affect health through other channels, which include social factors such as social cohesion, social integration, unhealthy lifestyles, and natural factors like high temperature and precipitation. Because of the difficulty in obtaining data on these factors, they were excluded from this study, and future studies may attempt to take them into account when analyzing the mechanisms of the impact of urbanization on public health.

6. Conclusions

Using panel data of 275 prefecture-level cities in China from 2011 to 2020, this study has determined the relationships between new-type urbanization, environmental pollution and public health from the perspectives of both local effects and spatial spillover effects and revealed that there exists a regional heterogeneity in the relationship between the three. The results of the study show that there is a ‘positive U-shaped’ relationship between new-type urbanization and public health in terms of both effects across China; there is an ‘inverted U-shaped’ relationship between new-type urbanization and environmental pollution only in terms of local effects; environmental pollution plays a partial mediating role in the impact mechanism of new-type urbanization on public health; and finally only a few cities in China have crossed the inflection point of new-type urbanization, most of them located in the eastern regions.

Moreover, our findings also uncover the overall regional heterogeneity across the east, central and west China in the relationships between new-type urbanization, environmental pollution and public health, especially the significant heterogeneity between the east and central China, in spite of the homogeneity between the western part and the whole country. In this respect, our study has contributed to the further elaboration of the relationships between new-type urbanization, environmental pollution and public health empirically, which can be used for China and other countries confronting the issue of balancing environmental conservation and improvement of public health in the wake of sustainable urbanization strategies in the future.

Author Contributions: Y.Z. (Yili Zhang) and R.W. (Ruonan Wang) conceptualized the paper. R.W. (Ruonan Wang) and K.W. performed the statistical analysis and drafted the manuscript. Y.Z. (Yuechi Zhang) and Y.H. conducted the research and data collection. R.W. (Rangke Wu) re-reviewed and co-revised the manuscript from the English language perspective. B.L. and Y.Z. (Yili Zhang) reviewed and edited the writing. All authors made significant intellectual contributions to multiple revisions of the draft. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Guangdong Province Philosophy and Social Science Planning 2020 Project (GD20CGL23), the Guangdong Provincial Philosophy and Social Sciences Planning 2023 General Project (GD23CGL09), and the 2023 Project of the 14th Five-Year Plan for the Development of Philosophy and Social Sciences in Guangzhou (2023GZGJ108).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data used in this study are available on the official websites of the National Bureau of Statistics of China (http://www.stats.gov.cn/tjsj/ndsj/, accessed on 3 July 2022), the Health and Health Commission of the People’s Republic of China (http://www.nhc.gov.cn/, accessed on 4 July 2022), and the standard map service website of the National Bureau of Surveying, Mapping and Geo-graphic Information (http://bzdt.ch.mnr.gov.cn, accessed on 11 June 2022).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Abbreviations

HL	Level of public health
EPI	Environmental pollution level
NUI	New-type Urbanization Index
PPA	Level of population aging
HES	Share of health expenditure
RTG	Proportion of the population employed in the tertiary sector
SDM	Spatial Durbin Model
SLM	Spatial Lag Model
SEM	Spatial Error Models
LR	Likelihood ratio test

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