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Inequality and heterogeneity in medical resources for children with autism spectrum disorders: a study in the ethnic minority region of southern China

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Abstract

Background In recent years, medical interventional treatment for children with autism spectrum disorder (ASD) has been gradually introduced in medical institutions in the Guangxi Zhuang Autonomous Region in southern China. However, the allocation of these medical resources has been uneven. This study describes the spatial allocation of medical resources for children with ASD in Guangxi, evaluates their supply and utilization, and expounds on their correlations with socioeconomic and demographic conditions.

Methods This study was based on a special survey conducted from 2021 to 2022 by the Guangxi Disabled Rehabilitation Research Center. The number of medical institutions for children with ASD (MIIs), average number of ASD technicians per 10,000 target people (CTPP), and coverage rate of medical interventions (CMI) were set as dependent variables, while population density, proportion of town residents, total retail sales of consumer goods, disposable income per capita gross domestic product per capita (GDPpc), and number of enterprises above designated size were set as independent variables, all of which were included in the spatial statistical model. The main analysis methods was multiscale geographically weighted regression (MGWR).

Results The allocation of MIIs (Moran's $I = 0.119$, $p = 0.007$), CTPP (Moran's $I = 0.208$, $p = 0.017$), and CMI (Moran's $I = 0.251$, $p = 0.004$) in Guangxi showed significant spatial autocorrelation. The medical resources formed high-value hot spots in major districts of core cities, while the medical resources were scarce in some remote ethnic minority counties and densely populated areas in southeastern Guangxi. MIIs showed significant spatial correlations with

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population density (*EV*=-0.225, $p=0.001$), proportion of town residents (*EV*=0.255, $p=0.002$), total retail sales of consumer goods (*EV*=0.806, $p<0.001$), and disposable income per capita (*EV*=-0.267, $p<0.001$). CTPP showed significant correlations with population density (*EV*=0.211, $p=0.019$), GDPpc (*EV*=0.267, $p=0.002$), total retail sales of consumer goods (*EV*=0.382, $p<0.001$), and number of enterprises above designated size (*EV*=-0.242, $p=0.005$). CMI showed a significant association with proportion of town residents (*EV*=0.415, $p<0.001$), total retail sales of consumer goods (*EV*=0.273, $p=0.006$), and number of enterprises above designated size (*EV*=-0.236, $p=0.003$).

Conclusions The spatial allocation of medical resources for children with ASD in Guangxi is heterogeneous, and correlates varyingly with regional socioeconomic conditions as well as urbanization and demographic conditions.

Keywords Autism spectrum disorder, Children, Medical resource, Spatial allocation, Heterogeneity, MGWR

Background

ASD severely affects the psychological development of children and adolescents and has a negative impact on their language, expression, learning, social, and self-care abilities [1–3]. According to a recent national study, the prevalence of ASD in children in China ranges from 0.64–0.74% [4], with the prevalence in the coastal provinces of southern China at around 0.62%, slightly lower than the national level [5]. Due to the severe consequences and heavy social and economic burden of the disease [6, 7], Chinese health authorities have gradually expanded the screening scope in recent years. Each year, hundreds of thousands of children with ASD cases are identified and diagnosed because of the large population base. With an increased understanding of ASD and advances in medical intervention techniques, Chinese health authorities are imposing greater and more complex demands on the available medical resources [8].

To address the issue of medical resources for children with ASD, the civil affairs and health authorities of Guangxi have been making efforts since 2015 to provide adequate medical resources for children with ASD by expanding the number and scale of medical institutions in the region through policy support and financial subsidies. As of December 2022, there were 255 medical institutions for children with ASD in Guangxi, of which 252(98.8%) institutions were registered and practicing, 1(0.4%) was in the process of approval and not yet operational, and 2(0.8%) were closed due to failure to meet assessment standards or heavy financial losses in 2020–2021. The 255 health institutions including public institutions sponsored by the government, such as medical rehabilitation centers for ASD, specialized clinics in public general hospitals or children's hospitals, special schools, and small institutions managed by non-governmental organizations or privately sponsored institutions. These institutions generally follow the behavioral and educational interventions recommended in the Guidelines for the Treatment and Rehabilitation of Children with ASD issued by the Health Care Commission of China, with a few advanced institutions exploring more innovative interventions and strategies on this basis.

The registration and approval of ASD medical service institutions in Guangxi are managed by the Guangxi Disabled Rehabilitation Research Center, which found that the number of large institutions registered and applying in core cities such as Nanning and Liuzhou was much greater than the numbers in remote mountainous areas, and many out-of-town guardians choose to seek treatment for their children at institutions in major cities. The heterogeneity in the spatial allocation of hospital resources has been elaborated in many studies [9], especially high-quality medical resources, which are mostly concentrated in metropolitan areas [10]. Inequality of medical resources affects people's physical and mental health directly or indirectly [11], and the essential cause of such inequality is socioeconomic and developmental disparities [12]. This study will draw on the methodologies and indicators of these studies, such as the number of institutions, the number of medical staff per capita, and the coverage rate, to describe the allocation, provision, and utilization of medical resources for children with ASD in Guangxi [13, 14].

Guangxi Zhuang Autonomous Region is located in the south of China, between 104°28 '-112°04' E and 20°54 '-26°23' N, bordering Vietnam to the southwest. It covers an area of about 237,600 square kilometers and has a population of 50.37 million. Guangxi is the only coastal autonomous region of ethnic minorities in southern China and the region with the largest population of Zhuang and Yao ethnic groups in the world. Figure 1-a shows that it borders Yunnan, Guizhou, Hunan and Guangdong provinces in China from west to southeast, and its geographical location is shown in Fig. 1-b.

Guangxi has a typical karst landform, with the elevation dropping from −76 m in the central basin to the highest 2093 m in the north. Karst landscape in Guangxi is mainly distributed in southwest, northwest, north and northeast, accounting for 80% of the total area, and the main rivers in Guangxi are Yujiang, Liujiang, Xiangjiang, Hongshui, and Xunjian, as shown in Supplementary Fig. 1-a. The administrative divisions of Guangxi include 41 municipal districts, 70 counties and 12 ethnic minority counties. The capital city of Guangxi is Nanning, which is

Fig. 1 The geographic locations of Guangxi and China are shown in Figures a and b, respectively

located in the central part of Guangxi and includes the main municipal districts of Qingxiu, Xixiangtang, Jiangnan and Xingning. The administrative areas, railroad and road transportation networks are presented in Supplementary Fig. 1-b.

According to 2021 statistics, Guangxi's GDP per capita is about US $7,627.9, much lower than neighboring Guangdong Province (US $15,240.3), and also lower than inland provinces such as Hunan (US $10,744.2) and Yunnan (US $8,914.7). This economic disparity directly affects the distribution of medical resources, especially in remote ethnic minority areas, where the accessibility and quality of medical resources are significantly lower than in urban areas [10, 42, 43].

Due to historical inheritance, social changes, and severe karst topography, Guangxi shows significant heterogeneity in socioeconomic development, with the south-central plains areas being far more developed than the northwestern and northern karst mountains. Regional socioeconomic conditions may have an effect on the allocation of ASD medical resources, which in turn affects the health outcomes of the children with ASD [15]. At the same time, the population of ethnic minorities in Guangxi has surpassed 18 million. The linguistic landscape in Guangxi is highly complex, encompassing over ten dialects and their variants, such as Cantonese (spoken by approximately 23.3 million people), Southwest Mandarin (approximately 12 million), Hakka (around 3 million), and Zhuang (about 9 million). In addition to Mandarin, these dialects belong to different linguistic systems and are not mutually intelligible as shown in Supplementary Table (1) In terms of spatial distribution, many cities and their affiliated counties are home to multiple dialects and language varieties simultaneously, as shown in Supplementary Table (2) Previous studies have demonstrated the adverse effects of belonging to ethnic minority groups and speaking their languages on ASD medical treatment [16, 17].

This study aims to explore the spatial features of the allocation of ASD medical resources in Guangxi, uses multi-scale geographically weighted regression (MGWR) to explore and analyse the spatial correlation between demographic, socioeconomic, geographical conditions, and medical resources for children with ASD. The findings may provide valuable insight for the government into ways to improve the medical resource allocation policies for ASD.

Subjects and methods

Data source

Information on ASD institutions registered and practiced in Guangxi was obtained from a special assessment survey conducted by the GXDRRC in 2021–2022, and data were collected, including (1) the location, number, and type of ASD institutions in the district; (2) the levels of institutions, defined by Departments of China Disabled Persons' Federation as Level 1, Level 2, and Level 3, depending on the capacity to provide medical services to children with ASD cases each year (level 1: 20–79, level 2: 80–159, level 3: ≥160) and the number of medical technicians (level1: 5–10, level 2: 10–15, level 3: >15); (3) the number of technical staff directly involved in medical interventions for ASD; and (4) the average number of ASD cases treated per year in 2019–2021. It should be additional noted that more than half of the ASD institutions (50.4%, 127/252) in Guangxi rely on the children's health divisions of grades 2–3 public hospitals, Chinese hospitals are classified into 1–3 grades according to their size as follows: Grade 3 hospitals are large general hospitals at provincial and municipal level with more than 501 beds, Grade 2 hospitals are general hospitals at county or district level with 100–500 beds, and Grade 1 hospitals are small primary hospitals located in rural communities with less than 100 beds.

We collected information registers for all 254 registered ASD institutions in Guangxi as of 1 December 2022; 2 institutions had closed, leaving 252 registered and practising ASD institutions in Guangxi, of which the numbers of Level 3, Level 2, and Level 1 institutions were 38(15.1%), 59(23.4%), and 155(61.5%), respectively, and the numbers of technicians directly engaged in medical interventions for ASD in Level 3, Level 2, and Level 1 institutions were 1,162(43.6%), 887(33.3%), and 616(23.1%), respectively. The average number of cases treated in ASD institutions during 2019–2022 was 4,947(37.8%) in Level 3 institutions, 4,659(35.6%) in Level 2 institutions, and 3,479(26.6%) in Level 1 institutions.

The demographic and socioeconomic indicators considered in this study include (1) population density, (2) proportion of the population under 14 years old, PU14, (3) proportion of town residents, (4) years of schooling per capita, (5) gross domestic product per capita, (6) disposable income per capita, (7) total retail sales of consumer goods, (8) general public budget revenue, and (9) number of enterprises above designated size. These data were collected from the Guangxi Bureau of Statistics as of December 31, 2021 [18]. The indicators were set as independent variables in the regression model. The units in this study are metric, and the conversion of economic indicators is based on an average exchange rate of 6.452:1 between the Chinese yuan and the U.S. dollar in 2021 [19].

This study covers 41 municipal districts, 70 counties, and 12 ethnic minority counties in 14 prefecture-level cities within the administrative jurisdiction of Guangxi Zhuang Autonomous Region. The classification of the 12 ethnic minority counties in Guangxi is based on the Law of the People's Republic of China on Regional Ethnic Autonomy, issued by the State Council of China, and related administrative division documents. The primary characteristic of these autonomous counties is their high proportion of ethnic minorities in the total population. The specific classification criteria include: (1) the proportion of ethnic minorities exceeds 30%; (2) approval by the State Council to designate the county as a ethnic minority county.

In this study, ordinary counties are those that are not classified as 'ethnic minority counties'. This study also distinguishes between municipal districts of provincial capital cities, which are those within the city limits of Nanning, and municipal districts of other cities, which are those within the city limits of prefectural-level cities other than Nanning.

The area covered by this study is all counties and districts within the administrative jurisdiction of the Guangxi Zhuang Autonomous Region, and the format of the digital map is the shp file of ArcGIS. The coordinate system of the digital map is set to the World Geodetic System 1984 (WGS1984), and the spatial scale is set to the county level. The digital elevation model used to calculate the average elevation and estimate terrain was downloaded from NASA's EARTHDATA project.

Independent and dependent variables

The number of people aged 0–14 years was set as the denominator, and the number of technical staff directly involved in medical interventions for ASD was set as the numerator to calculate the average number of children ASD technicians per 10,000 target people (CTPP), which reflects the current status of medical intervention resources for ASD in the county or district.

The prevalence measured by Zhou H et al. during the period from 2014 to 2016 was used to estimate possible cases of children ASD in each county and district [4], and the average number of ASD treated per year was divided by the number of possible cases to calculate the coverage rate of medical interventions (CMI), which reflects the current status of the availability of standardized medical interventions for ASD in the county or district.

The CTPP and CMI indicators were used as dependent variables, and the demographic and socioeconomic indicators were set as independent variables in the spatial regression model.

Methods and software

The following spatial statistical analysis approaches were followed in this study: (a) Spatial autocorrelation was conducted for Moran's *I* index, Z score, and p values to measure the spatial autocorrelation features of dependent and independent variables. Moran's *I* index was employed to evaluate the clustering or dispersion pattern of spatial data, with positive values indicating a positive spatial correlation (i.e., high values are adjacent to high values and low values are adjacent to low values), negative values indicating a negative spatial correlation (i.e., high values are adjacent to low values), and approaches 0 indicating a spatial random distribution. In this study, Moran's I index was used to assess whether there is significant spatial autocorrelation in the spatial distribution of ASD medical resources in Guangxi. (b) Hot-spot analysis (Getis-Ord Gi*) was adopted to identify significant high-value (hot spot) and low-value (cold spot) clusters in spatial data, displaying hotspots and cold spots with high or low Z-scores, respectively [20, 21]. By calculating the Z-score for each region, hotspot analysis determined which areas had values significantly higher or lower than their surrounding regions. The threshold for the Z-value was 1.976, where a Z-value greater than or equal to 1.976 indicated significant spatial clustering ($p < 0.05$), which signified the presence of high-intensity clustering on a digital map [20]. Hotspot analysis not only revealed the over-concentration or insufficient distribution of ASD medical interventions but also provided a basis for prioritizing resource allocation. (c) Global spatial trend analysis was applied to evaluate the characteristics of the spatial allocation trends of medical intervention resources and coverage for ASD based on 2D and 3D perspectives [22]. By analyzing the overall trend of spatial data, this method revealed the spatial change law of resource allocation and helped to identify the high-value and low-value regions of resource allocation. (d) Density-based cluster analysis was conducted to determine the spatial clustering patterns of ASD medical resources [23]. By identifying the density distribution in the data, this method effectively captured the clustering characteristics of resources in space and helped to identify the core region and the edge region of resource allocation. (e) The spatial regression relationships of the independent and dependent variables were evaluated using MGWR and plotted as digital maps to visualize the spatial regression relationships. In contrast to classical ordinary least squares regression (OLS), MGWR takes into account spatial dependence and/or spatial heterogeneity in the data, allowing the regression coefficient to vary with space, thereby capturing spatial heterogeneity. OLS assumes that the regression coefficient is constant throughout the study area, while MGWR can identify the difference in the influence of independent variables on dependent variables in different regions. In this study, MGWR was used to analyze the spatial heterogeneity of socioeconomic and demographic factors on the allocation of medical resources in ASD, and revealed the differentiated effect of these factors on resource allocation in different regions. In a multi-scale geographically weighted regression (MGWR) model, estimates (*EV*s), ranges, and P-values are used to assess the influence of independent variables on dependent variables. The estimated value (*EV*), range, and *p* value in the MGWR model were used to assess the effect of the independent variable on the dependent variable. EV is a statistical parameter with directional characteristics, and its positive or negative sign indicates the positive or negative effect of the independent variable on the dependent variable. Standard residuals (*SR*), Akaike information criterion (*AIC*), corrected Akaike information criterion (*AICc*), Schwarz Bayesian information criterion (*BIC)*, and adjusted R^2 (adj. R^2) were used to evaluate the effectiveness of the MWGR model [24, 25]. The data management and analysis statistical software in this study were EXCEL, Rstudio v4.4.43, ArcGIS Pro V3.0.1, and MGWR V2.2.

Results

Medical resources, estimated cases, and medical intervention coverage rate for ASD in Guangxi

The spatial allocation of high-quality ASD resources is highly concentrated, with only 15 of the 41 main municipal districts having Level 3 ASD interventions, of which 47.4% (18/38) are located in the four main municipal districts of Nanning and the other 52.6% (20/38) in the other 11 municipal districts, as shown in Table 1. There were 12 areas with no ASD medical institutions, including 2 municipal districts (4.9%, 2/41), 8 ordinary counties (13.8%, 8/58), and 2 ethnic minority counties (16.7%, 2/12). Of the 252 ASD institutions, 188 (74.6%) were government-sponsored public institutions, and 64 (25.4%) were private-sponsored institutions.

The number of ASD technicians was higher in the main municipal districts than in the ordinary and minority counties; the distribution of the data is presented in Fig. 2-a. By extrapolation, the variability in CTPP values was relatively large, ranging from 0.62 to 26.2 in municipal districts, 0.35 to 3.87 in ordinary counties, and 0.43 to 3.47 in minority counties, as shown in Fig. 2-b.

The prevalence of ASD in children in China was estimated to be approximately 0.7% based on Zhou's study [4, 26]. The estimated number of ASD cases in Guangxi ranged from 141 to 3,125 at the county level and from 93 to 2,026 in municipal districts owing to the wide variation in the baseline population, as shown in Fig. 2-c. The coverage of ASD medical interventions ranged from 4.55 to 179.2% in municipal districts, 2.54–24.05% in ordinary

Table 1 Allocation of levels 1 to 3 ASD medical intervention institutions, technical staff, and average number of ASD cases served in Guangxi

Institution levels	Districts or counties				Sponsors		Technical staffs	ASD cases served per year
	Municipal districts of provincial capital[1]	Municipal districts of other cities[2]	Ordinary Counties[3]	Ethnic Minority Counties[4]	Government-sponsored	Private-sponsored		
Level 3	18(47.4)	20(52.6)	0(0)	0(0)	33(86.8)	5(13.2)	1162(43.6)	4947(37.8)
Level 2	4(6.8)	45(76.3)	7(11.9)	3(5.0)	42(71.2)	17(28.8)	887(33.3)	4659(35.6)
Level 1	4(2.6)	32(20.7)	105(67.7)	14(9.0)	113(72.9)	42(27.1)	616(23.1)	3479(26.6)
total	26(10.3)	97(38.5)	112(44.4)	17(6.8)	188(74.6)	64(25.4)	2665	13,085

Note:

1. Municipal districts of the provincial capital are those within the city limits of Nanning

2. Municipal districts of other cities are those within the city limits of prefectural-level cities other than Nanning

3. Ordinary Counties are those that are not classified as 'ethnic minority counties'

4. The Ethnic Minority Counties are defined by the state Council of China in accordance with the the Law of the People's Republic of China on Regional Ethnic Autonomy

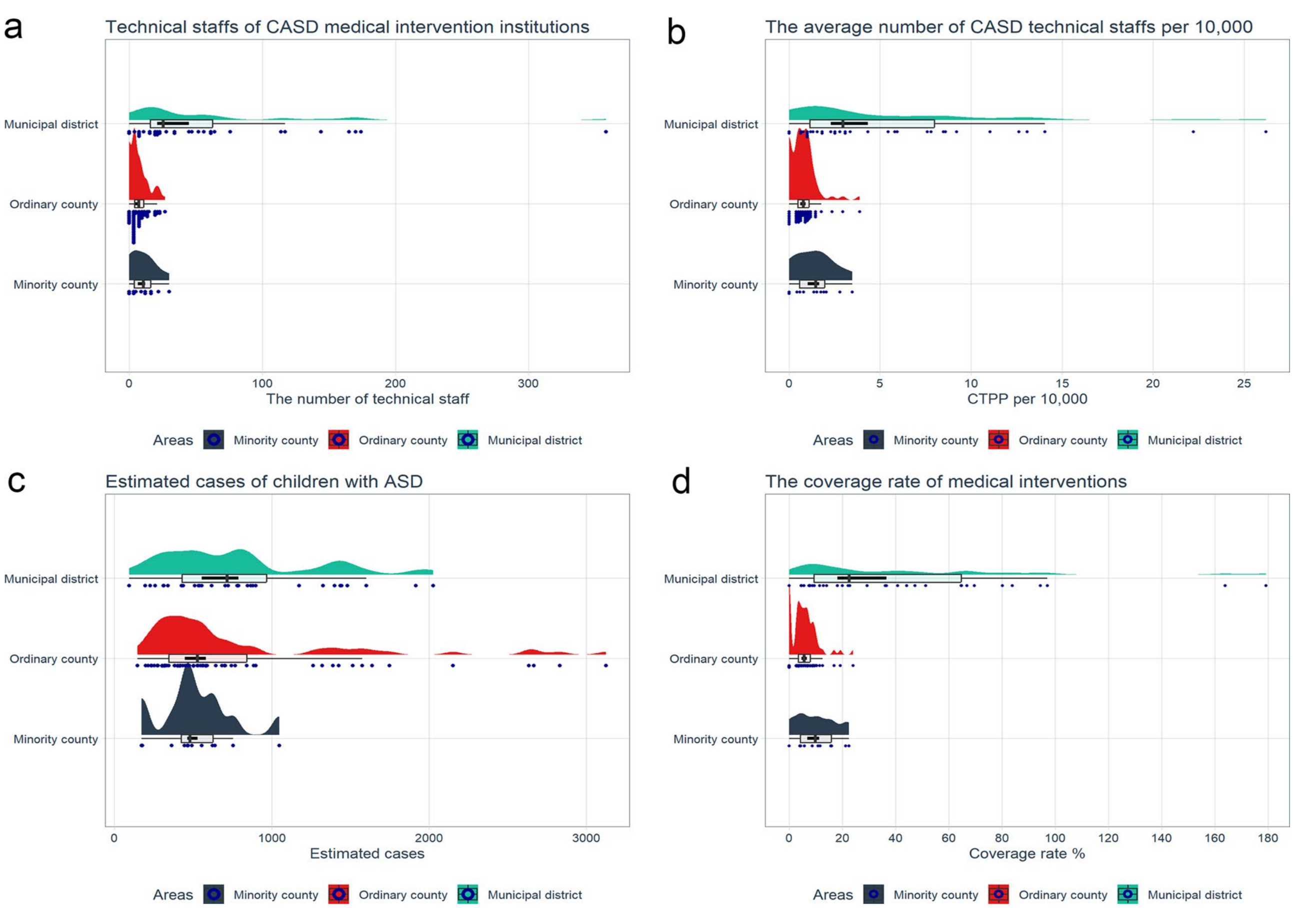

Fig. 2 The data characteristics of technical staff of ASD medical intervention institutions, average number of ASD technical staff per 10,000 people, estimated number of ASD cases, and coverage rate of medical interventions are shown in **a**, **b**, **c**, and **d**, respectively

counties, and 4.07–22.54% in minority counties, as shown in Fig. 2-d.

Unbalanced development and status of demographic and socioeconomic conditions in Guangxi

The development of social, economic, cultural and demographic indicators in Guangxi is quite unbalanced; the population density in the mountainous areas in the north and northwest is less than 100 per km^2, while the population density in the central and southeastern plains is close to 7,000 per km^2, as shown in Fig. 3-a.

In the major municipal districts of Nanning (Qinxiu, Xixiangtang, Jiangnan, and Xingning), Liuzhou (Chenzhong, Yufeng, Liunan, and Liubei), Guilin (Diecai, Qixing, and Xiufeng), and Wuzhou (Wanxiu and Changzhou), the proportion of the PU14 ranges from 10 to 17%, which is lower than in other regions or counties, but the proportion of town residents (84.3–100%) and the average schooling years (11–13 years) are higher in these municipal districts than in other regions, as shown in Fig. 3-b. The main municipal districts of Nanning, Liuzhou, Guilin, Wuzhou, and Yulin (Yuzhou) also have higher economic indicators, such as GDPpc, disposable income per capita, total retail sales of consumer goods, general public budget revenue, and number of enterprises above designated size, than other counties, as shown in Fig. 3-c and -d. All the independent variables presented significant spatial correlation ($p < 0.05$). Except for PU14, the independent variables expressed significant spatial aggregation ($p < 0.05$), as shown in Table 2.

Spatial heterogeneity and patterns of ASD medical resources in Guangxi

High-quality Level 3 ASD medical intervention resources were located mainly in Xixiangtang, Qingxiu, and Xingning districts in Nanning; Chengzhong district in Liuzhou; Gangbei district in Guigang; Yuzhou district in Yulin; and Haicheng district in Beihai, and there was significant spatial autocorrelation (Moran's $I = 0.119$, $p = 0.007$) and aggregation (general $G = 0.019$, $p = 0.001$) in the spatial distribution of ASD medical interventions, as shown in Table 3; Fig. 4-a. Significant spatial hot spots were observed in Xixiangtang, Qingxiu, Xingning, Chengzhong, Gangbei, Yuzhou and Haicheng, as shown in Fig. 4-b.

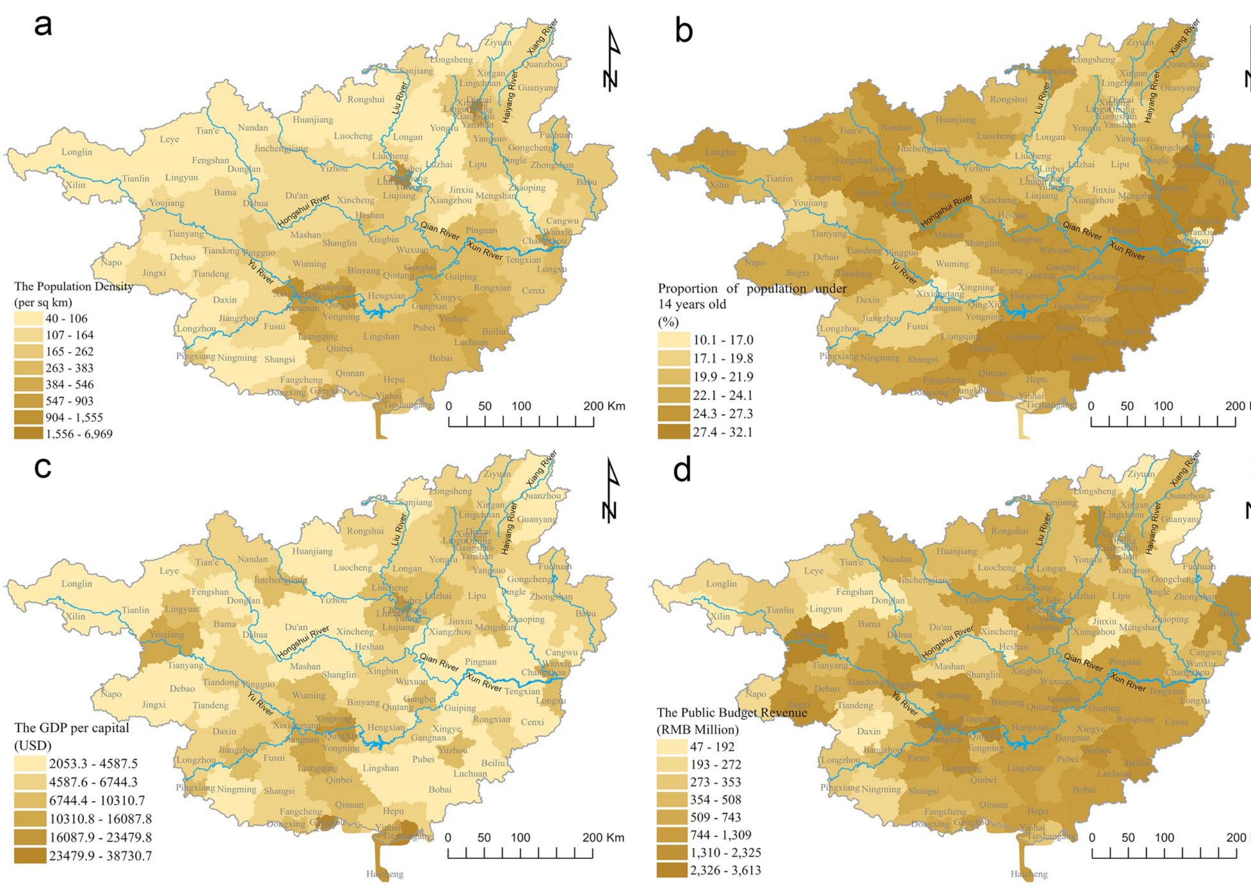

Fig. 3 The spatial patterns of the population density, proportion of population under 14 years old, GDPpc, and the public budget revenue are shown in **a**, **b**, **c** and **d**, respectively

Table 2 Spatial autocorrelation and Getis-Ord general G analyses of demographic and economic indicators

Independent variables	Spatial autocorrelation			Getis-Ord General G		
	Moran's I	Z-score	*p*	General G	Z-score	*p*
1. Demographic indicators						
population density (per sq. km)	0.435	7.121	< 0.001	0.029	7.641	< 0.001
proportion of the population under 14 years old (%)	0.550	8.235	< 0.001	0.009	1.731	0.083
proportion of town residents (%)	0.386	5.816	< 0.001	0.010	6.496	< 0.001
years of schooling per capita (years)	0.530	7.950	< 0.001	0.009	5.056	< 0.001
2. Economic indicators						
GDPpc (USD)	0.291	4.662	< 0.001	0.012	4.980	< 0.001
disposable income per capita (USD)	0.209	3.239	0.001	0.009	2.581	0.010
total retail sales of consumer goods (million USD)	0.323	5.089	< 0.001	0.016	5.515	< 0.001
general public budget revenue (million USD)	0.258	4.025	< 0.001	0.016	5.515	< 0.001
number of enterprises above designated size (million USD)	0.326	5.013	< 0.001	0.012	4.456	< 0.001

Table 3 Spatial autocorrelation and Getis-Ord general G analyses of ASD medical sources and coverage

Dependent variables[1]	Spatial autocorrelation			Getis-Ord General G		
	Moran's I	Z-score	*p*	General G	Z-score	*p*
MIIs[1] (scores)	0.119	2.689	0.007	0.019	3.386	0.001
CTPP[2] (per 10,000)	0.208	2.395	0.017	0.012	2.640	0.008
CMI[3] (%)	0.251	2.847	0.004	0.012	2.915	0.004

Note:

1. MIIs, means the number of medical institutions for children with ASD

2. CTPP, means the average number of ASD technicians per 10,000 target people

3. CMI, means the coverage rate of medical interventions

The high CTPP values were distributed mostly in the Xixiangtang, Qingxiu, Xingning, Chengzhong, Liunan, Xiufeng, Wanxiu, Yuzhou, Jinchengjiang, Youjiang, Gangbei and Haicheng municipal districts, which formed an 'island phenomenon' with the surrounding low-value counties, as presented in Fig. 4-c. The spatial distribution of CTPP showed significant spatial autocorrelation (Moran's $I = 0.208$, $p = 0.017$) and aggregation (general $G = 0.012$, $p = 0.008$), as shown in Table 3, and formed hot spots in the districts of Xixiangtang, Xingning, Chengzhong, Xiufeng, Wanxiu, and Haicheng, as shown in Fig. 4-d.

The spatial distribution pattern of CMI was quite similar to that of CTPP, and the island phenomenon was more obvious in comparison, as in Youjiang in the west, Gangkou, and Yinhai in the south, and Yuzhou in the southeast. The spatial distribution of CMI also showed significant spatial autocorrelation (Moran's $I = 0.251$, $p = 0.004$) and aggregation (*general* $G = 0.012$, $p = 0.004$), as shown in Table 3, and formed hot spots in Xixiangtang, Qingxiu, Xingning, Chengzhong, Xiufeng, Wanxiu, and Haicheng district.

Spatial trend of ASD medical resources in Guangxi

The spatial allocation of ASD medical intervention institutions showed a trend of low north and high south, ascending and then descending from west to east, as shown in Fig. 5-a, and higher Z values in central and south-central Guangxi were observed in the 3D trend map, presented in Fig. 5-b.

The spatial allocation of CTPP indicators was characterized by an increasing and then decreasing trend from southwest to northeast, with a gradual increase from south to north, and showed a significant area of low Z values in the southeast, as shown in Fig. 5-c. In the 3D trend map, high and low Z values appear in the central and southeastern regions of Guangxi, respectively, as presented in Fig. 5-d.

The CMI spatial trend was similar to the CTPP, but the variance in the trend coefficients was higher, with an overall increase from southwest to northeast, a greater range of significance in the south than in the CTPP, and a smaller area of low values in the southeast than in the CTPP, as shown in Fig. 5-e. In the 3D trend digital map, significant high Z values were visible in the central region and low Z values in the southeast, as shown in Fig. 5-f.

Spatial correlation between socioeconomic and demographic conditions and ASD indicators

Three MGWR models were constructed to assess the possible contribution of socioeconomic and demographic conditions to ASD-related indicators.

The geographical allocation of ASD medical institutions showed a significant spatial correlation with population density (EV=-0.225, $p = 0.001$), proportion of town residents ($EV = 0.255$, $p = 0.002$), total retail sales of

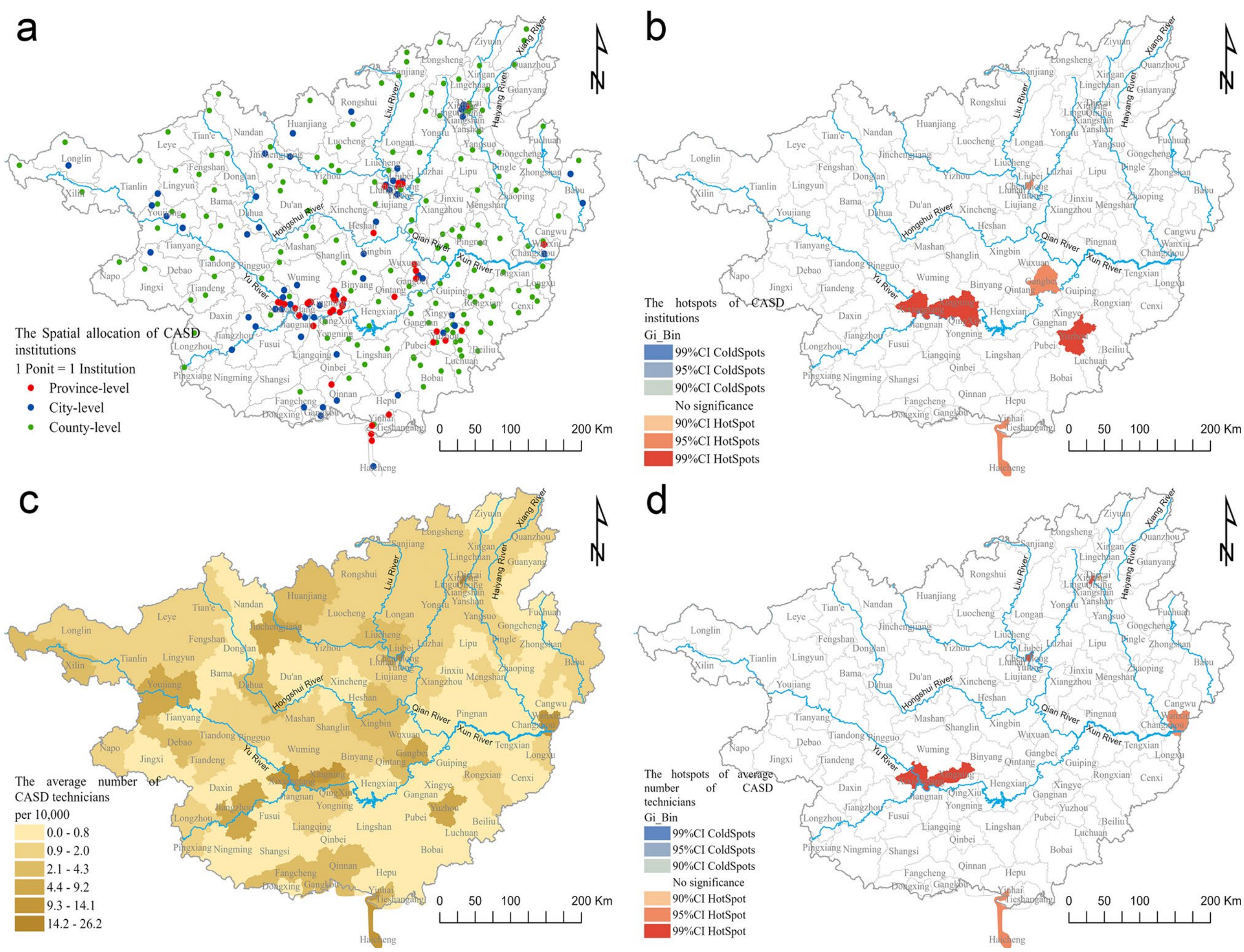

Fig. 4 The spatial allocations of CASD medical intervention institutions and average number of ASD technicians per 10,000 people (CTPP) are shown in **a** and **c**, respectively. The results of the hot-spot analysis corresponding to these indicators are shown in **b** and **d**, respectively

consumer goods (EV = 0.806, p < 0.001), and disposable income per capita (EV=-0.267, p < 0.001). The proportion of town residents (bandwidth = 103, 95% CI: 68–105) showed a wider range of effects on the spatial allocation of medical institutions than total retail sales of consumer goods (bandwidth = 50, 95% CI: 48–68), disposable income per capita (bandwidth = 50, *95% CI*: 48–68), and population density (bandwidth = 48, *95% CI*: 46–52).

The geographical allocation of CTPP showed significant spatial correlations with population density (EV = 0.211, p = 0.019), GDPpc (EV = 0.267, p = 0.002), total retail sales of consumer goods (EV = 0.382, p < 0.001), and number of enterprises above designated size (EV=-0.242, p = 0.005), with population density (bandwidth = 107, *95% CI*: 68–107) and total retail sales of consumer goods (bandwidth = 107, *95% CI*: 68–107) showing a wider range of effects on CTPP than GDPpc (bandwidth = 81, 95% CI: 68–93) and the number of enterprises above designated size (bandwidth = 46, 95% CI: 44–58).

The spatial distribution of CMI showed a significant spatial association with proportion of town residents (EV = 0.415, p < 0.001), total retail sales of consumer goods (EV = 0.273, p = 0.006), and number of enterprises above designated size (EV=-0.236, p = 0.003) and a potential association with GDPpc (EV = 0.166, p = 0.072). The proportion of town residents (bandwidth = 107, *95% CI*: 83–107) and total retail sales of consumer goods (bandwidth = 107, *95% CI*: 68–107) had a wider range of effects on CMI indicators than the number of enterprises above designated size (bandwidth = 46, *95% CI*: 44–68) and GDPPC (bandwidth = 93, *95% CI*: 68–99).

The model diagnostics showed that all three ASD indicators fit satisfactorily in the MGWR model. The MGWR model for ASD medical institutions ($AICc$ = 159.636, *adj.* R^2 = 0.791) was the best fit, with the lowest AICc and highest adj. R^2, and the MGWR models for the CTPP ($AICc$ = 240.210, *adj.* R^2 = 0.542) and CMI ($AICc$ = 234.938, *adj.* R^2 = 0.565) were similarly fitted, with

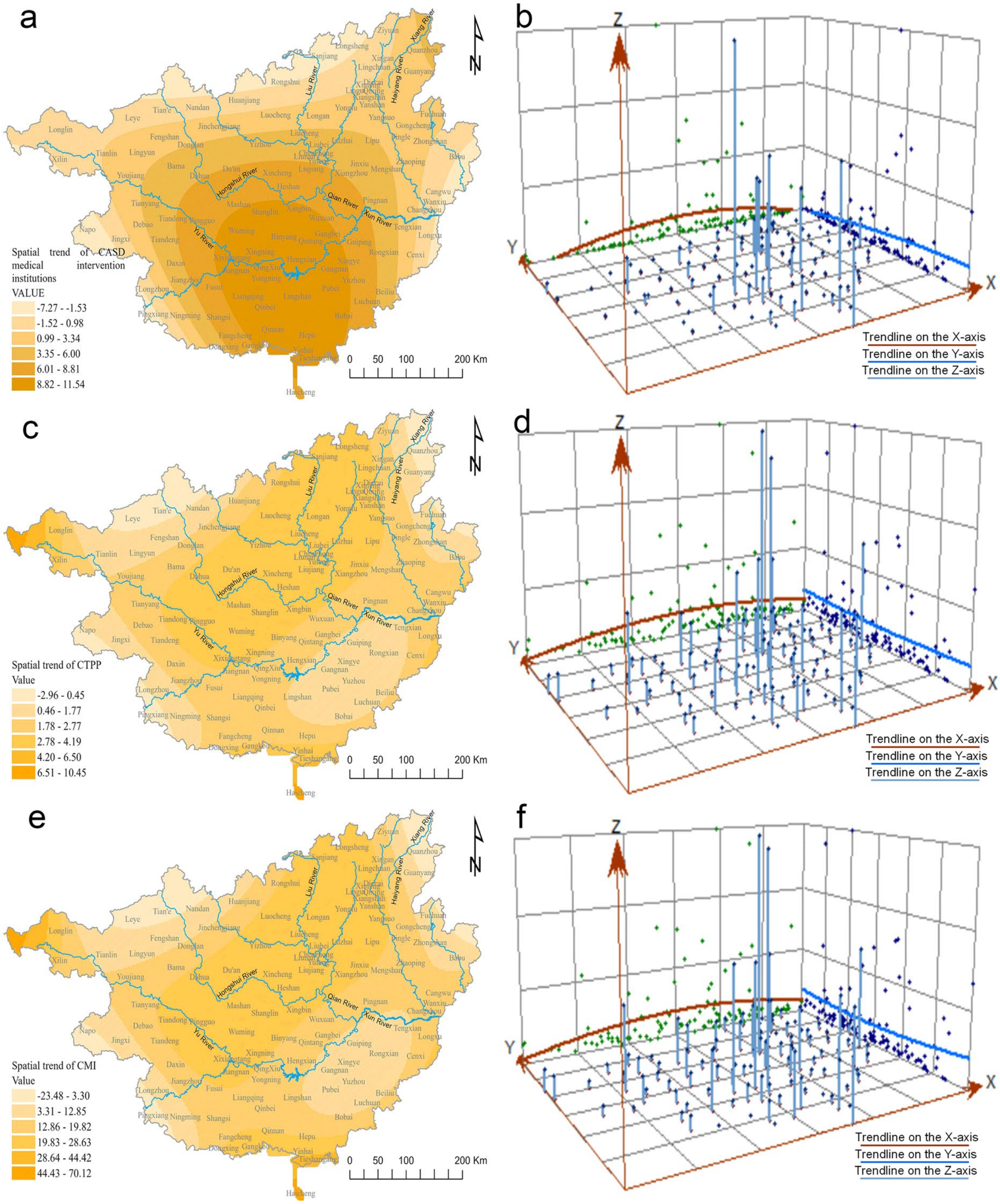

Fig. 5 The 2-dimensional and 3-dimensional distribution trends of ASD medical intervention institutions, CTPP, and CMI are shown in **a**–**b**, **c**–**d**, and **e**–**f**, respectively

similar *AICc* and adj. R^2. The detailed statistics for this section are shown in Table 4.

Visualization of MGWR model fitting outcomes

The MGWR model visualization results for ASD medical intervention institutions revealed that (1) the areas where the allocation of ASD medical intervention institutions was significantly associated with the population density were located in the central, south-central and northern areas of the map (p-value: 0.002 to 0.050); (2) a significant global association was found between the dependent variable and the proportion of town residents (p

Table 4 Multiscale geographically weighted regression (MGWR) of MIIs, CTPP, CMI, and socioeconomic and demographic conditions

Dependent Variables[1]	Bandwidth(95%CI)	Model statistical parameters				Model performance evaluation				
		EV	S.E	t(EV/S.E)	*p*-value	AIC	AICc	BIC	R^2	adj.R^2
1. MIIs[1]										
proportion of town residents	103(68,105)	0.255	0.084	3.046	0.002	153.937	159.636	196.253	0.820	0.791
total retail sales of consumer goods	50(48,68)	0.806	0.069	11.653	< 0.001					
disposable income per capita	50(48,68)	-0.267	0.059	-4.540	< 0.001					
population density	48(46,52)	-0.225	0.070	-3.216	0.001					
2. CTPP[2]										
population density	107(68,107)	0.211	0.090	2.340	0.019	236.796	240.210	269.876	0.590	0.542
total retail sales of consumer goods	107(68,107)	0.382	0.097	3.928	< 0.001					
GDPpc	81(68,93)	0.267	0.088	3.039	0.002					
number of enterprises above designated size	46(44,58)	-0.242	0.086	-2.826	0.005					
3. CMI[3]										
proportion of town residents	107(83,107)	0.415	0.108	3.829	< 0.001	231.362	234.938	265.200	0.612	0.565
total retail sales of consumer goods	107(68,107)	0.273	0.099	2.763	0.006					
GDPpc	93(68,99)	0.166	0.093	1.796	0.072					
number of enterprises above designated size	46(44,68)	-0.236	0.080	-2.959	0.003					

Note:

1. MIIs, means the number of medical institutions for children with ASD
2. CTPP, means the average number of ASD technicians per 10,000 target people
3. CMI, means the coverage rate of medical interventions

value: <0.001 to 0.002); (3) it was significantly correlated with the disposable income per capita in the central and southwestern areas of the map (p value: <0.001 to 0.05); and (4) it was significantly associated with the total retail sales of consumer goods in the central, southern, eastern and most of the western areas of the map (p value: <0.001 to 0.05), as shown in Fig. 6a and d.

The MGWR model visualization results for CTPP revealed that (1) the areas where CTPP was significantly associated with the proportion of town residents were located in the northeastern, southeastern, and southern areas of the map, where population density was high (p value: 0.044 to 0.050); (2) CTPP was significantly associated with GDPPC in most regions except Qinbei, Qinnan district, Fangchenggang, and Dongxing in the south (p value: <0.001 to 0.050); (3) CTPP showed significant global correlation with the total retail sales of consumer goods (p value: <0.001 to < 0.001); and (4) CTPP and number of enterprises above designated size were significantly associated in the northern part of the map (p value: <0.001 to < 0.050), as shown in Fig. 7a and d.

The visualization results of the MGWR model for CMI revealed that (1) CMI was globally significantly associated with the proportion of town residents (p value: <0.002 to 0.052), with the exception of Xilin County in the northwest; (2) areas where CMI was significantly associated with the number of enterprises above designated size were located in the central and northern regions of the map (p value: <0.001 to 0.050); (3) CMI was globally significantly associated with the total retail sales of consumer goods (p value: <0.001 to 0.002); (4) CMI was significantly associated with GDPPC in the central, northern, western and most of the eastern parts of the region (p value: <0.001 to 0.050); and the association was not significant in the southwestern part of the region, as presented in Fig. 8a and d.

Discussion

Many studies have pointed to spatial heterogeneity in the allocation of medical resources in China due to uneven economic development [10, 27]. The current study revealed that 100% of high-quality level 3 ASD institutions and 43.6% of professional staff for children with ASD were deployed in the main municipal districts of core cities in Guangxi far more than in the general counties and ethnic minority areas. In terms of geostatistics, these ASD medical resources showed significant spatial clustering in the major municipal districts of core cities, which is similar to the misallocation of medical resources in the ethnic minority areas of Southwest China [28, 29].

From a spatial viewpoint, we observed that municipal districts with high CTPP and CMI values were mostly surrounded by counties with low values, forming an 'island phenomenon' of high values, as in the Xixiangtang, Qingxiu, Xingning, Chengzhong, Xiufeng, Wanxiu, Yuzhou, Yinhai and Youjiang districts. As a result of receiving large numbers of out-of-town ASD from surrounding counties, CMI indicators in these municipal districts exceeded 100% and even approached 200%. We hypothesize that this phenomenon is due to the superior healthcare resources available in urban areas, which make these regions more attractive to parents of children with ASD. Additionally, the accessibility of ASD treatment is further enhanced by the convenient

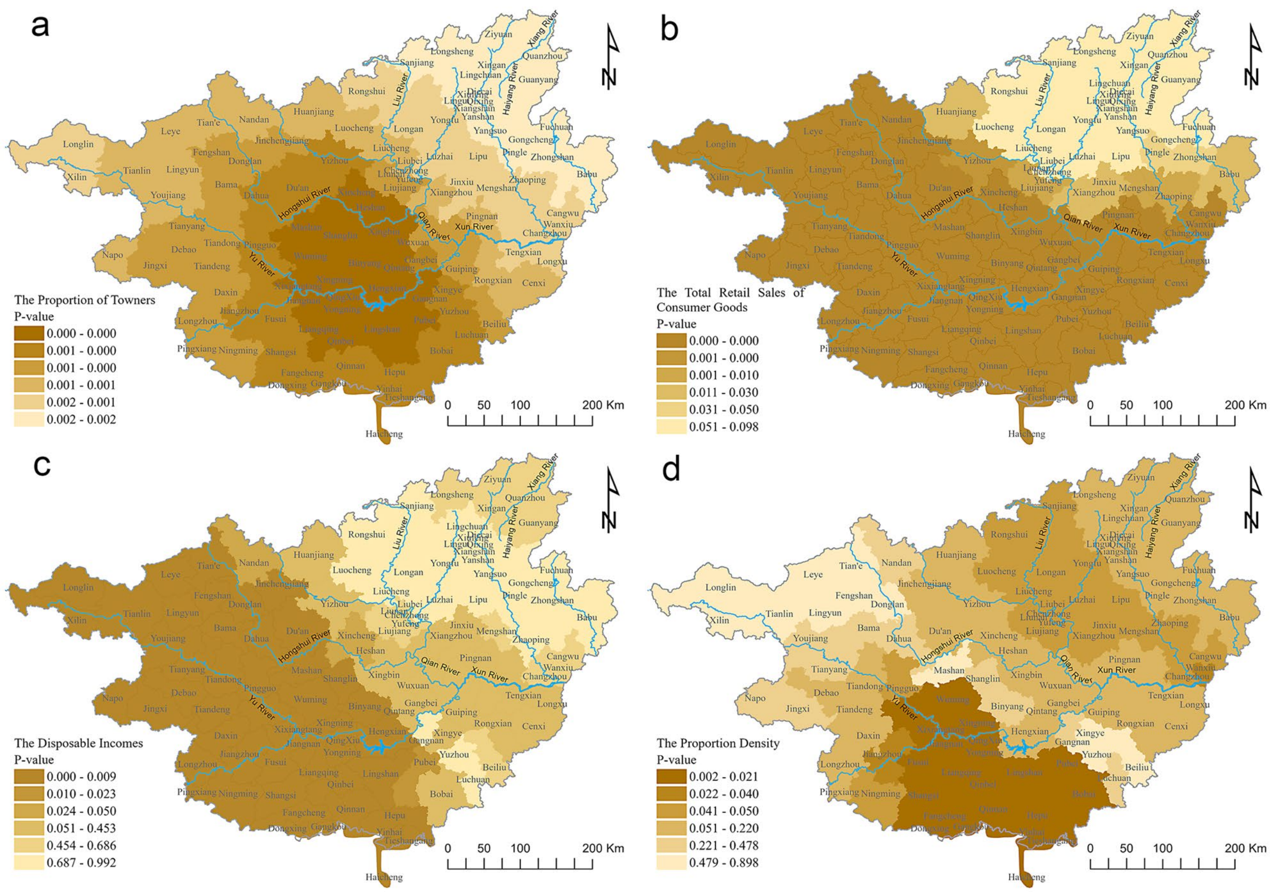

Fig. 6 The spatial regressions between demographic and economic indicators and ASD medical intervention institution resources in the MGWR. The significant areas of proportion of town residents, total retail sales of consumer goods, disposable income per capita, and population density in MGWR models are shown in **a**, **b**, **c**, and **d**, respectively

transportation networks in urban areas [30, 31]. Regional disparities in treatment coverage were a common feature of HIV epidemiological studies, such as 11% in southwestern China and 21% in Beijing in 2008, with 10% of people with HIV/AIDS preferring to be treated in higher-level hospitals in major cities, even though HAART was available at the primary level [32], and public health policies that appraise government departments have contributed to this indicator reaching 90% in 2019 [33, 34]. It may be feasible to draw on these approaches to reduce the regional disparities in ASD intervention coverage in Guangxi.

The huge range in CMI in the current study indicates four aspects: first, the strong demand for high-quality ASD medical resources from the children's parents; second, the overloading of advanced ASD institutions in these municipal districts; and third, the fact that children treated off-site are often accompanied and cared for by lower-educated grandparents, while the children's parents choose to work in their home county to ensure income, and the absence of parental intervention may have a negative effect on ASD treatment outcomes [35]; and four, the language barriers associated with the diverse and complex regional dialects of Guangxi may affect the effectiveness of off-site medical interventions [17]. Meanwhile, the reduction in numbers of local ASD cases as a result of off-site therapy may also slow the development of local ASD resources [36].

Compared to the abundant ASD medical resources in the core cities' major municipal districts, there were varying degrees of scarcity in ASD resource allocation in some counties, which can be classified as resource-based shortages and supply-based shortages. The former are caused by the absence of ASD resources in certain ethnic minority or border counties in southwestern and northeastern Guangxi. The latter are attributable to a large population base that leads to a scarcity of resources per capita, because of the uneven distribution of China's population [37]. Thus, the trend analysis of CTPP and CMI revealed a phenomenon of 'islands' of low values in this area, which suggested that resources for ASD resources need to be matched in areas with larger population bases.

Despite Guangxi's 1,628.6 km of coastline and abundant nonferrous metal resources, its hilly karst landscape

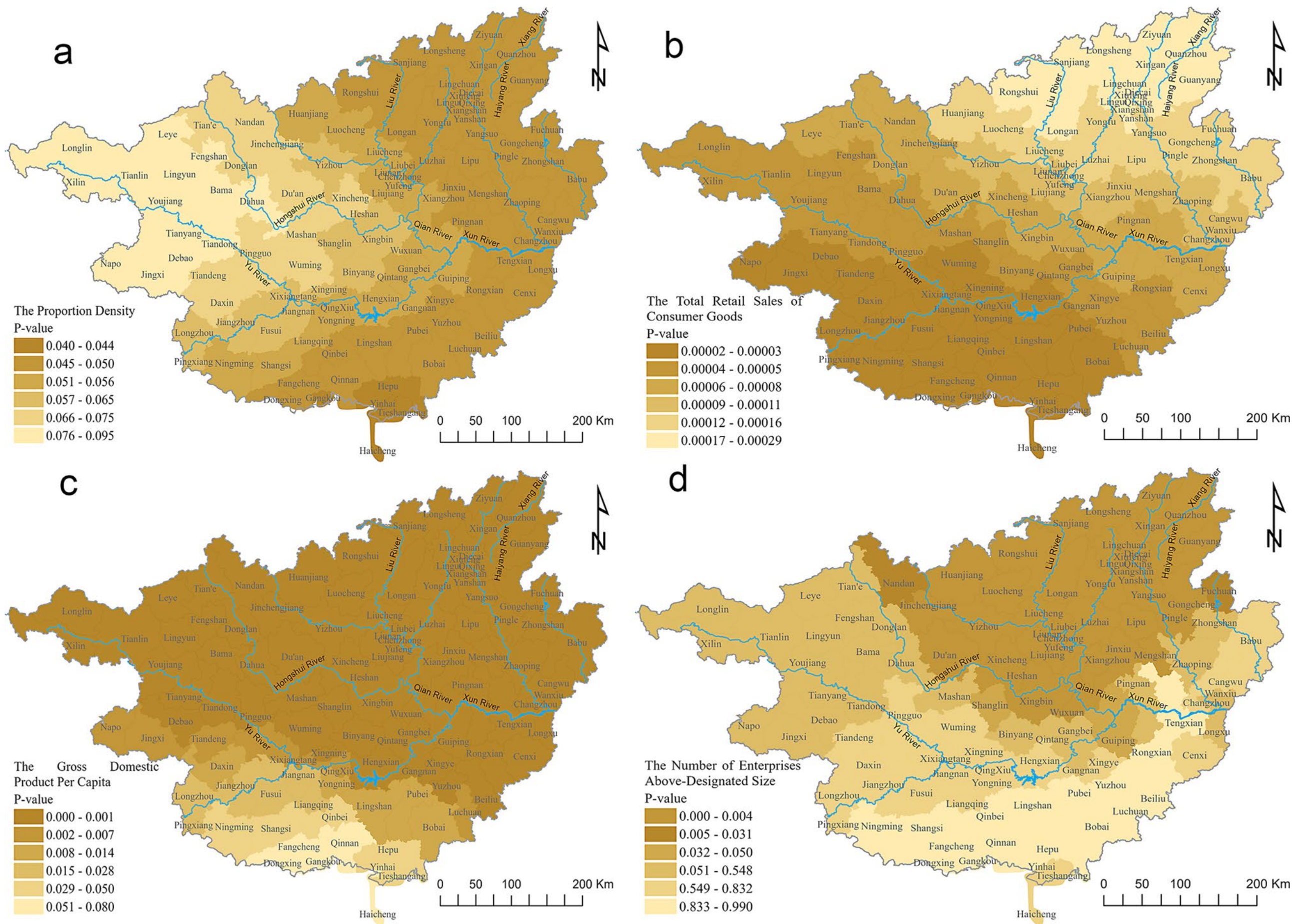

Fig. 7 The spatial regressions between demographic and economic indicators and the average number of ASD technicians per 10,000 people (CTPP) in the MGWR. The significant areas of population density, total retail sales of consumer goods, gross domestic product per capita, and number of enterprises above designated size in the MGWR models are shown in **a**, **b**, **c**, and **d**, respectively

has led to sluggish economic development. With a GDPPC of approximately US$7,627.9 in 2021, Guangxi is lower than the US$10,744.2, US$7,875.9, and US$8,914.7 of the inland provinces of Hunan, Guizhou, and Yunnan, respectively, and much lower than the US$15,240.3 of the neighbouring coastal province of Guangdong [38–41]. Many previous studies have revealed that socioeconomic conditions have direct or indirect effects on the allocation of medical resources [10, 42, 43], but few studies have addressed the association between socioeconomic and demographic indicators and the spatial allocation of ASD medical resources. To address this issue, we introduced the MGWR model, which has been widely applied in Eco-epidemiological studies [44, 45], and found that the proportion of town residents showing the greatest correlation with the spatial allocation of ASD medical institutions. The allocation of medical resources in China has been vastly unequal [46], and although fairness has gradually improved [47], medical resources in metropolitan cities are still much higher than those in other regions, due to the government financial subsidies being 3–4 times higher than in other regions [48]. Most of the Level 3 ASD institutions in Guangxi were operated by large provincial or municipal hospitals in the core municipal districts, which are characterized by a high degree of urbanization and consumption levels, similar to the positive socioeconomic impact on the distribution of hospitals [49].

The CTPP, used to estimate the number of ASD professionals and technicians per capita in the 0-14-year-old target group, was similar to the general per capita medical resources, with significant heterogeneity in spatial allocation [50]. The MGWR model indicated that CTPP was positively correlated with population density, GDPpc and total retail sales of consumer goods. Currently, approximately 75% of ASD medical institutions in Guangxi are government-sponsored, nonprofit public institutions, and most of these institutions rely on women's and children's hospitals and rehabilitation centres for disabled people. The operation of ASD institutions and the salaries and subsidies of professional and technical staff come from financial allocations and

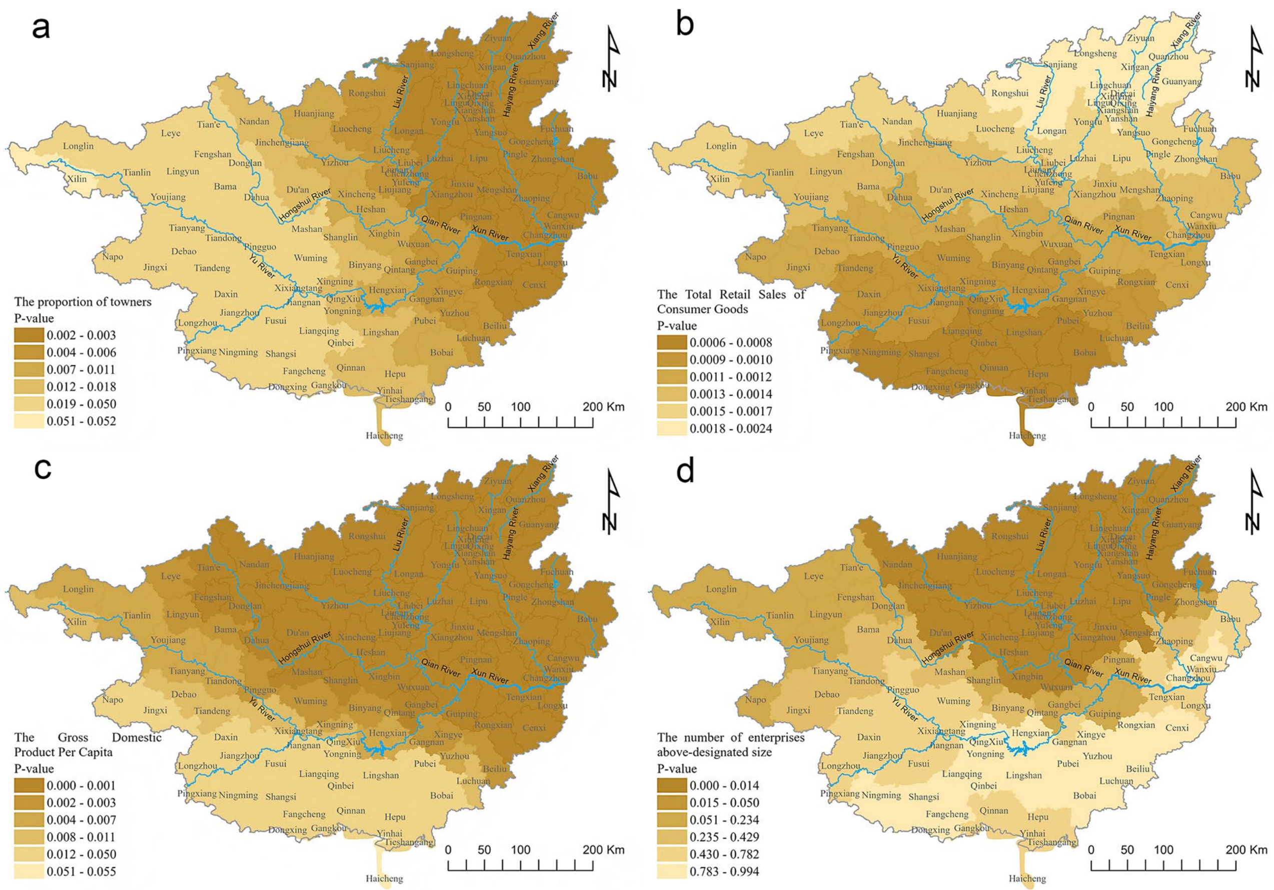

Fig. 8 The spatial regressions between demographic and economic indicators and the coverage rate for ASD medical interventions (CMI) in the MGWR. The significant areas of proportion of town residents, total retail sales of consumer goods, gross domestic product per capita, and number of enterprises above designated size in the MGWR models are shown in **a**, **b**, **c**, and **d**, respectively

require significant financial support [7, 51]. GDPpc and total retail sales of consumer goods directly reflect the regional economic status, and show a global positive correlation with CTPP. the positive effect of economic level on medical resources has been explored in depth [52, 53]. It is worth noting that the number of enterprises above designated size reflected the number of medium to large enterprises in each region, which were a major source of local government revenue, but it was negatively correlated with the CTPP indicator in this study. For reasons of environmental protection and green economy policies [54, 55], many large enterprises in China are deployed in exclusive economic development zones or industrial parks located away from urban areas, which we believe has led to a negative association with CTPP.

The health effects of medical resource allocation on regional populations have been confirmed in a number of studies [56]. The CMI indicator is used to evaluate the extent to which local ASD populations receive medical interventions and to analyse the potential effect that the availability of medical resources may have on local ASD populations. The proportion of town residents, total retail sales of consumer goods, and GDPpc have a positive spatial correlation with CMI, and we suggest that the correlation was related to the abundance of high-quality ASD medical institutions in the main municipal districts. As in the MGWR model for CTPP. Both the total retail sales of consumer goods and GDPpc showed significant associations with the dependent variable, with approximate positive effects on CTPP and CMI, suggesting a possible general correlations between economic conditions and ASD healthcare resources. The total retail sales of consumer goods showed positive statistically significant correlations in all three MGWR models, and we suggest that it played a large role in the allocation of resources and coverage effects of medical interventions for ASD and, in some way, reflected the regional population's capacity to cope with the heavy burden of ASD [7, 57].

In this paper, we have revealed that socioeconomic conditions may have a complex and integrated effect on ASD medical resources. Taking into account that the proportion of government-funded public institutions among ASD institutions in Guangxi is as high as 75%, we suggest that socioeconomic conditions are more likely to have indirectly influenced the allocation of ASD resources by affecting local government revenues and budgets, and have led to uneven and inequitable allocation. However, the development of socioeconomic conditions is a long and complex process, and the adverse natural environment of remote ethnic minority areas further adds to such difficulties.

There is a clear difference in efficiency between public and private healthcare institutions. For instance, the Guangxi Rehabilitation and Research Centre for Persons with Disabilities, a typical public healthcare intervention institution, took more than five years to complete the process of government planning, health sector approval, and financial investment, construction, and operation. This lengthy investment and construction cycle of public institutions significantly limits the flexibility of their medical intervention services. In contrast, private healthcare organizations can become operational and provide services to children with ASD within one and a half years by renting space.

Therefore, we suggest that (1) the government and health authorities should increase special investment in areas with scarce medical resources for ASD through the financial transfer payment system, especially in economically backward remote ethnic minority areas; (2) in densely populated areas in southeastern Guangxi with better economic conditions, health authorities should promote public medical institutions to assume their social responsibility to increase the allocation of ASD resources to meet the local demand for medical interventions for ASD; and (3) the flexibility and efficiency of the private institutions makes them more adept at finding gaps in the market for services, and health authorities should support private institutions participation in ASD medical services.

The government can support private institutions through the following mechanisms: first, establish a flexible fiscal transfer payment system, where health departments purchase medical services from private institutions to address gaps in resources and service coverage; second, optimize medical insurance policies by including private services in the reimbursement system, enhancing accessibility and sustainability; and third, through policy guidance and regulation, ensure that private institutions maintain their market-driven advantages while providing high-quality services that align with public interests.

There are limitations in this paper. First, it is essentially an ecoepidemiological study and includes a limited set of socioeconomic indicators, which might inevitably lead to some bias in the conclusions at this stage. Second, since the National Bureau of Statistics of China has not released detailed data for the 2020 census, ASD estimation can only be inferred from the numbers of adolescent children aged 0–14 years listed by local statistical bureaus, which may lead to bias in ASD estimation. Third, the study includes a limited number of variables that are commonly used demographic indicators, and others not included in this study may also have an impact on ASD healthcare resources, so this study is inevitably somewhat limited. Fourth, although this study combines multiple spatial analysis methods to explore spatial correlations when possible, settings of some parameters (such as spatial resolution, bandwidth, and significance level) may still affect the results. Additionally, in subsequent research phases, machine learning algorithms will be used to further quantify and explain how economic, policy, and demographic factors influence the allocation of resources. Despite these shortcomings, this paper reveals possible problems in the allocation of ASD medical resources in economically disadvantaged ethnic minority areas and the socioeconomic conditions that may impact them, and it visualizes the complex correlations of socioeconomic conditions on the spatial allocation of medical resources in ASD through the currently popular MGWR model. The findings of the current study may provide valuable insight and evidence for other regional ASD resource allocation issues.

Conclusions

The spatial allocation of ASD medical resources in Guangxi is uneven, with core cities having abundant resources but remote counties and densely populated southeastern areas in Guangxi having an insufficient supply of ASD resources. Regional socioeconomic conditions, urbanization levels, and population density have different and complex correlations with the spatial allocation of ASD resources. The Guangxi government and health authorities should improve the allocation of ASD resources by financial supports and administrative measures to improve the equity and accessibility of ASD medical services.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-22871-5.

Supplementary Material 1: Supplementary Fig 1. The typical karst landscapes, rivers and transport road networks in Guangxi are shown in Supplementary Figures 1a and b, respectively.

Supplementary Material 2

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Author contributions
YY Lin, HX Lu, GZ Chen, and J Qin contributed to conception and design of the study. YY Lin, HX Lu, CB Luo, and M Chen, organized the database. YY Lin and HX Lu performed the statistical analysis. YY Lin, HX Lu, and J Qin drafted and revised the manuscript. RF Qin, JS Jiang, WW Tan, Q Huang, LL Huang, and AH Dong wrote sections of the manuscript. YY Lin, HX Lu, and GZ Chen contributed equally to the current work. All authors contributed to manuscript revision, read, and approved the submitted version.

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Data availability
The datasets and information presented in the current work can be downloaded from the official websites of the provincial statistical bureaus in China. The Guangxi ASD medical resources data can be obtained for reasonable and non-commercial purposes by contacting the corresponding author.

Declarations

Ethics approval and consent to participate
This study was approved by Medical Ethics Committee of the First Affiliated Hospital of Guangxi Medical University (3-SW001-01). All subjects who participated in the survey questionnaire of this study signed an informed consent form.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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