Hindawi
Andrologia
Volume 2023, Article ID 7416033, 11 pages
https://doi.org/10.1155/2023/7416033

Research Article

Spatial–Temporal Characteristics of Semen Quality in Infertile Men in Wenzhou, China during 2010–2018

Xuchao Dai,[1] **Mengqi Zhang**,[2] **Gang Chen**,[3] **Chengshuang Pan**,[4] **Jiujia Zheng**,[4] **Qianjin Fei**,[4] **Hong Huang**,[5,6] **and Zhigang Wu**[7,8,9]

[1]*The First Affiliated Hospital, School of Medicine, Zhejiang University, Hangzhou 310003, China*
[2]*School and Hospital of Stomatology, Wenzhou Medical University, Wenzhou 325027, China*
[3]*Hospital Infection Control Management Department, The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University, Wenzhou 325027, China*
[4]*Reproductive Medicine Center, The First Hospital of Wenzhou Medical University, Wenzhou 325000, China*
[5]*Center for Health Assessment, Wenzhou Medical University, Wenzhou 325035, China*
[6]*Zhejiang Provincial Key Laboratory of Watershed Sciences and Health, Wenzhou Medical University, Wenzhou 325035, China*
[7]*Department of Urology, The First Affiliated Hospital of Wenzhou Medical University, Wenzhou 325000, China*
[8]*The Quzhou Affiliated Hospital of Wenzhou Medical University, Quzhou People's Hospital, Quzhou 324000, China*
[9]*Reproductive Health Research Center, Health Assessment Center of Wenzhou Medical University, Wenzhou 325000, China*

Correspondence should be addressed to Hong Huang; huanghongpanda@163.com and Zhigang Wu; andrologywzg@wmu.edu.cn

Received 18 September 2023; Revised 19 October 2023; Accepted 21 October 2023; Published 9 November 2023

Academic Editor: Yong-Gang Duan

Background. Declining semen quality has become one of the most serious public health problems worldwide; however, the spatial–temporal characteristics of semen quality of infertile men remain unknown. *Objective*. To explore spatial–temporal characteristics of semen quality of infertile men in Wenzhou from 2010 to 2018 and thereby provide a scientific basis for development of strategies to enhance male reproductive health. *Methods*. We obtained 22,978 semen sample data from 2010 to 2018 from the Reproductive Medicine Center and Urology of the First Affiliated Hospital of Wenzhou Medical University in Wenzhou, China. Linear regression analyses and spatial autocorrelation analyses were used to study spatial–temporal characteristics of semen quality parameters. *Results*. Overall, from 2010 to 2018, mean values for total sperm number and semen volume showed linear increasing trends, and mean values for total sperm motility showed linear decreasing trend (all $P<0.05$). Cold spot analyses of progressive sperm motility, total sperm motility, and normal sperm forms were also in main urban area of Wenzhou (Lucheng District, Ouhai District, Longwan District, and Dongtou District) and hot spot were also in nonmain urban area of Wenzhou (mainly including Taishun County, Pingyang County, and Wencheng County). However, hot spot analyses of total sperm number and semen volume were mainly in Dongtou District. *Conclusions*. The main urban area is the "harder-hit area" of semen quality, while for the islands area is the "high-withdrawal area." Government departments need to pay more attention to improve male reproductive health in the main urban areas and actively control the potential influencing factors of male reproductive health, such as occupational exposure and life stress. Good environmental quality and plenty of seafood intake may be beneficial to semen quality.

1. Introduction

Semen quality is one of the common indicators for evaluating male reproductive health and an important basis for the diagnosis, treatment, and prevention of male infertility. However, studies in most parts of the world have shown a decreasing trend in semen quality parameters of local men [1–6], suggesting that the decline in semen quality has become one of the most serious public health problems in the world.

Several epidemiological studies reported significant geographic or regional variations in semen quality [7–12]. Palani et al. [13] found that American men presented lower sperm concentration, total sperm count, total sperm viability and progressive sperm viability, and higher total antioxidant capacity of semen compared to Iraqi men. In Nordic countries, a cross-

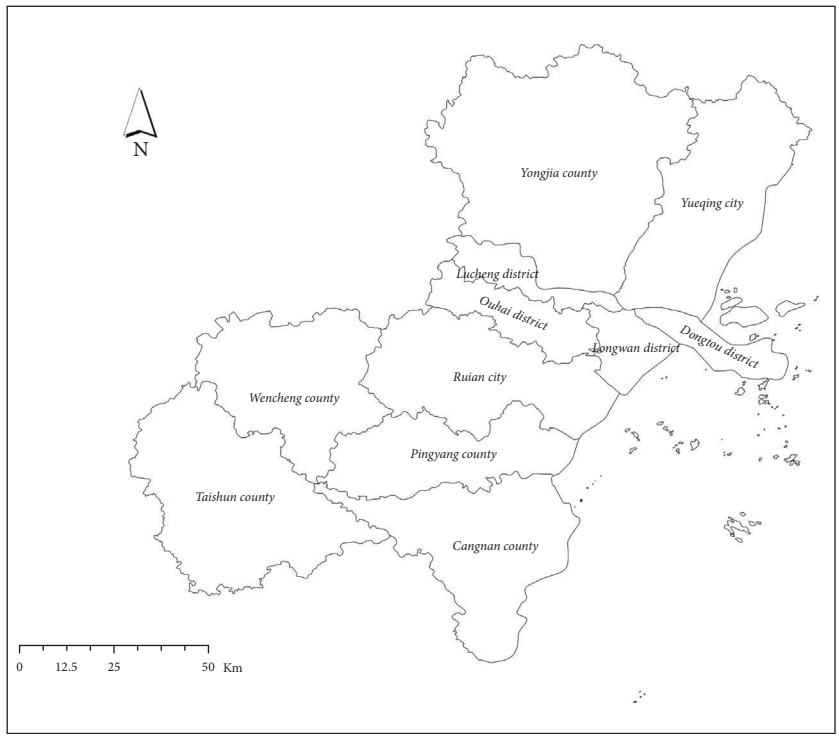


Figure 1: Geographical distribution of 11 county administrative divisions in Wenzhou, China.

sectional study [14] reported that Finnish men had a higher adjusted median percentage of motile sperm ($A+B+C$) than Danish men, and the proportion of men with low semen quality was lower in Finland (25.4%) than in Denmark (34.6%). Similarly, a retrospective cohort study in China reported statistically significant differences in sperm concentration among men at different latitudes in China [15]. However, these research methods used traditional epidemiological methods to compare differences between different regions. In addition, Zhang et al. [16] showed that traditional epidemiology cannot explore the spatial distribution characteristics of diseases and, therefore, need to use spatial epidemiological methods to study regional differences in semen quality. Moreover, these studies are to study the differences in semen quality parameters between large regions and lack the geographical distribution differences and associations of semen quality parameters between small regions.

Therefore, this study was the first to use spatial epidemiological, as well as traditional epidemiological methods to explore the spatial and temporal distribution of semen quality parameters of infertile men in Wenzhou City from 2010 to 2018, so as to provide clues for exploring the factors influencing the quality of semen and to provide scientific basis for the local government and the health management department to improve the level of male reproductive health of Wenzhou City at the regional level, as well as to provide a reliable reference for the prevention and control of infertile men in other regions.

2. Materials and Methods

2.1. Study Area. Wenzhou is located in the south of Zhejiang Province in eastern China, between 119°37′ E- 121°18′ E, 27°03′-28°36′ N. It is a prefecture-level city in Zhejiang Province with subtropical monsoon climate. Wenzhou is composed of 11 county-level administrative regions, namely Lucheng District, Longwan District, Ouhai District, Dongtou District, Ruian City, Yueqing City, Yongjia County, Cangnan County, Pingyang County, Wencheng County, and Taishun County, with about 9 million residents. The distribution of 11 county-level administrative regions in Wenzhou is shown in Figure 1.

2.2. Study Population. A retrospective study was conducted in the Reproductive Medicine Center and Urology of the First Affiliated Hospital of Wenzhou Medical University in Wenzhou, China. Since 2006, the center has established a database of all male patients' demographic characteristics (age, occupation, education level, and living area) and clinical information (semen quality parameters and semen analysis date). Between January 2010 and December 2018, we effectively included 22,978 infertile male patients after excluding patients with normal postmarital cohabitation and family history, organic diseases, spouse infertility, and missing information. All the wives of the included patients had normal fertility, but did not get pregnant again after 1 year of continuous unprotected intercourse. The patients in this study were deidentified and approved by the Ethics Committee of the First Affiliated Hospital of Wenzhou Medical University (KY2023-R194).

2.3. Semen Analysis. First, patients were asked to have to abstain from sex for 3–7 days before the semen quality test. Then, they collected semen samples by masturbation

in a private room into sterile cups and placed them in a 37°C incubator to liquefy. The technician observed the liquefaction of semen every 5–10 min and analyzed the semen sample immediately after liquefaction. We strictly followed the 5th edition of the World Health Organization (WHO) Laboratory Manual for the Examination and Processing of Human Semen [17]. We assessed semen volume (ml) by the weighing method; normal sperm forms (%) by the Pap staining method; and total sperm number (10^6), progressive sperm motility (%), and total sperm motility (%) by a computer-assisted semen quality analysis system (MICROPTIC S.L. Company, Viladomat, Barcelona, Spain). In addition, our laboratory rigorously implemented both in-house quality control and interroom quality control, as detailed in our previous studies [18]. According to the WHO 5th criteria [17], semen is defined as normal if it meets all the following requirements: progressive sperm motility $\geq 32\%$, total sperm motility $\geq 40\%$, total sperm number $\geq 39 \times 10^6$, semen volume ≥ 1.5 ml, and normal sperm morphology $\geq 4\%$; failure to satisfy one or more of these is defined as abnormal.

2.4. Statistical Analyses. The variables of demographic characteristics were described by frequency and percentage, while age was also described by mean and standard deviation. Semen quality parameters were described by mean, standard deviation, and percentile. For the time trend of each semen quality parameter, a linear regression model was used for analysis. For the spatial analysis of each semen quality parameter, spatial autocorrelation analysis was used, including global autocorrelation analysis and local autocorrelation analysis. The local autocorrelation analysis included local indicators of spatial association (LISA) aggregation diagram and local *G* statistics, and the specific spatial analysis method was described in Supplement 1. All statistical analyses were performed in Microsoft Excel (version 2013, Microsoft Corp., Redmond, WA, USA), GraphPad Prism version 8, and ArcGIS (version 10.0, ESRI Inc., Redlands, CA, USA). All statistical tests were two-sided tests, and statistical significance was defined as $P < 0.05$.

3. Results

3.1. Patient Characteristics. The demographic characteristics of the infertile male patients are summarized in Table 1. A total of 22,978 infertile male patients with a mean age of 32.5 ± 5.6 years were included, more than half of them were 30–35 years of age (34.5%), and majority were worker (85.9%) or education level of high school and lower (79.6%).

3.2. Semen Quality Parameters. The semen quality parameters of the infertile male patients are described in Table 2. The progressive sperm motility was $45.4 \pm 23.9\%$, the total sperm motility was $53.1 \pm 26.1\%$, the total sperm number was $224.4 \pm 228.2 \times 10^6$, the semen volume was 3.0 ± 1.5 ml, and the normal sperm forms were $2.9 \pm 3.5\%$. Among these five semen quality parameters, except for the normal sperm forms, the rest were above the WHO standards [17].

3.3. Temporal Trends of Semen Quality Parameters. The temporal trends of five semen quality parameters are shown in Figure 2. From 2010 to 2018, mean values for total sperm number ($R^2 = 0.6993$, $P = 0.005$, $\beta = 13.22$) and semen volume ($R^2 = 0.5752$, $P = 0.0179$, $\beta = 0.055$) showed linear increasing trends, and mean values for total sperm motility ($R^2 = 0.5018$, $P = 0.0327$, $\beta = -0.9283$) showed linear decreasing trend.

3.4. Spatial Patterns of Semen Quality Parameters. The global spatial autocorrelation analyses of mean semen quality parameters of infertile men showed that the parameters were randomly distributed in Wenzhou from 2009 to 2018 (Table 3). Moreover, most of the global spatial autocorrelation analysis of the annual mean of each parameter also showed that the parameters are randomly distributed (Tables S1–S5).

LISA analyses of mean semen quality parameters of infertile men showed that HL cluster of progressive sperm motility was in Longwan District, HH cluster of total sperm motility was in Cangnan County, HL cluster of total sperm number was in Ouhai District, HL cluster of semen volume was in Yongjia County and Taishun County, and LH cluster of semen volume was in Lucheng District and Wencheng County (Figure 3). However, the LISA analysis results of mean semen quality parameters from 2010 to 2018 were inconsistent with the yearly LISA analysis results of mean semen quality parameters for most years (Figures S1–S5).

Cold/hot spot analyses of mean semen quality parameters of infertile men showed that cold spot of progressive sperm motility and total sperm motility was in Dongtou District and hot spot was in Taishun County, cold spot of total sperm number was in Longwan District and hot spot was in Taishun County, and cold spots of normal sperm forms were in Ouhai District, Longwan District, and Dongtou District (Figure 4). The yearly cold spot analyses of progressive sperm motility, total sperm motility, and normal sperm forms were also in main urban area of Wenzhou (Lucheng District, Ouhai District, Longwan District, and Dongtou District) and hot spot was also in nonmain urban area of Wenzhou (mainly including Taishun County, Pingyang County, and Wencheng County) (Figures S6, S7, and S10). However, yearly hot spot analyses of total sperm number and semen volume were mainly in Dongtou District (Figures S8 and S9).

4. Discussion

Semen quality parameters are one of the important parameters for clinical evaluation of male reproductive health. However, many global studies have reported a decreasing trend in semen quality parameters, which imply that there may be an increasing trend in the number of infertile men. Therefore, for regional health-related departments, exploring the temporal trends and spatial distribution of semen quality parameters of infertile men is the primary task to understand and improve the reproductive health of local men. This study analyzed the spatial and temporal distribution characteristics of five semen quality parameters (progressive sperm motility, total sperm motility, total sperm number, semen volume, and normal sperm forms) of 22,978 infertile men in Wenzhou from 2010 to 2018. To our knowledge, this is the first

Table 1: Demographic characteristics of study patients.

Characteristics	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Total	2,405	2,487	2,434	2,589	2,599	2,357	3,057	2,715	2,335	2,2978
Age, years, *n* (%)										
≤25 years	104 (4.3)	93 (3.7)	106 (4.4)	108 (4.2)	112 (0.4)	88 (3.7)	153 (5.0)	98 (3.6)	65 (2.8)	927 (4.0)
25 years < age ≤ 30 years	805 (33.5)	781 (31.4)	785 (32.3)	808 (31.2)	873 (3.4)	772 (32.8)	939 (30.7)	825 (30.4)	670 (28.7)	7,258 (31.6)
30 years < age ≤ 35 years	882 (36.7)	895 (36.0)	900 (37.0)	961 (37.1)	909 (3.5)	823 (34.9)	927 (30.3)	832 (30.6)	795 (34.0)	7,924 (34.5)
35 years < age ≤ 40 years	450 (18.7)	533 (21.4)	483 (19.8)	500 (19.3)	499 (1.9)	450 (19.1)	603 (19.7)	558 (20.6)	490 (21.0)	4,566 (19.9)
Age > 40 years	164 (6.8)	185 (7.4)	160 (6.6)	212 (8.2)	206 (0.8)	224 (9.5)	435 (14.2)	402 (14.8)	315 (13.5)	2,303 (10.0)
Age	32 (5.0)	32.3 (5.0)	32.1 (5.0)	32.3 (5.1)	32.1 (5.2)	32.5 (5.5)	32.7 (7.0)	33.4 (5.9)	33.4 (5.8)	32.5 (5.6)
Occupation, *n* (%)										
Worker	2,102 (87.4)	2,341 (94.1)	2,295 (94.3)	2,450 (94.6)	2,354 (9.1)	2,170 (92.1)	2,528 (82.7)	1,848 (68.1)	1,649 (70.6)	19,737 (85.9)
Peasant	37 (1.5)	30 (1.2)	28 (1.2)	26 (1.0)	96 (0.4)	41 (1.7)	81 (2.6)	13 (0.5)	5 (0.2)	357 (1.6)
Intellectual	55 (2.3)	22 (0.9)	23 (0.9)	36 (1.4)	69 (0.3)	78 (3.3)	180 (5.9)	310 (11.4)	313 (13.4)	1,086 (4.7)
Businessman	156 (6.5)	56 (2.3)	64 (2.6)	62 (2.4)	67 (0.3)	41 (1.7)	118 (3.9)	285 (10.5)	252 (10.8)	1,101 (4.8)
Others	55 (2.3)	38 (1.5)	24 (1.0)	15 (0.6)	13 (0.1)	27 (1.1)	150 (4.9)	259 (9.5)	116 (5.0)	697 (3.0)
Education, *n* (%)										
High school and lower	1,958 (81.4)	2,143 (86.2)	2,013 (82.7)	2,001 (77.3)	2,223 (8.6)	1,935 (82.1)	2,448 (80.1)	2,035 (75.0)	1,533 (65.7)	18,289 (79.6)
Junior college	281 (11.7)	216 (8.7)	303 (12.4)	432 (16.7)	216 (0.8)	243 (10.3)	329 (10.8)	318 (11.7)	403 (17.3)	2,741 (11.9)
Undergraduate and higher	166 (6.9)	128 (5.1)	118 (4.8)	156 (6.0)	160 (0.6)	179 (7.6)	280 (9.2)	362 (13.3)	399 (17.1)	1,948 (8.5)

Data were given as *n* (%), except that age is given as mean (standard deviation). Column percentages may not add up to 100 due to rounding.

Table 2: Summary of semen parameters for the study subjects.

Parameter	Mean (standard deviation)	Percentile				
		Median	5th	25th	75th	95th
Progressive sperm motility (%)	45.4 (23.9)	49.1	0.0	30.5	63.1	78.3
Total sperm motility (%)	53.1 (26.1)	58.4	0.0	38.7	72.5	86.3
Total sperm number ($\times 10^6$)	224.4 (228.2)	171.6	0.0	46.6	323.4	656.6
Semen volume (ml)	3.0 (1.5)	2.6	1.0	2.1	3.9	5.6
Normal sperm forms (%)	2.9 (3.5)	2.2	0.0	0.5	4.4	8.8

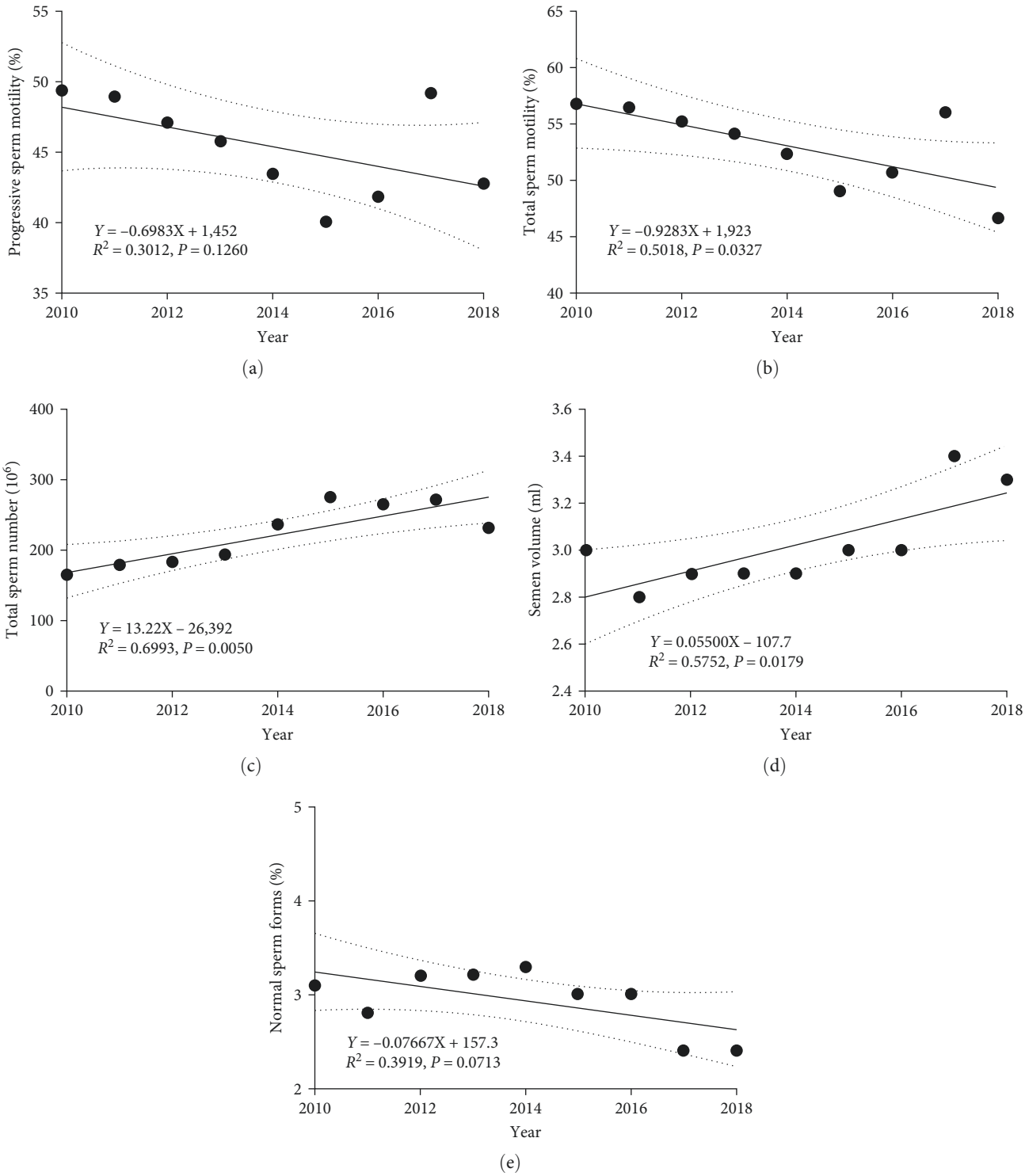


Figure 2: The linear regression lines of the annual average of semen quality parameters from 2010 to 2018. (a) Mean progressive sperm motility and (e) mean normal sperm forms were a liner trends with no significance. (b) Mean total sperm motility was declining year by year and showed a linear trend. (c) Mean total sperm number and (d) mean semen volume were increasing year by year and showed a linear trend.

Table 3: Global spatial autocorrelation analysis of mean semen quality parameters of infertile men in Wenzhou from 2009 to 2018.

Parameter	Moran's I	Z-value	P-value
Progressive sperm motility (%)	−0.127	−0.142	0.887
Total sperm motility (%)	−0.061	0.207	0.836
Total sperm number ($\times 10^6$)	−0.121	−0.110	0.912
Semen volume (ml)	−0.300	−1.124	0.261
Normal sperm forms (%)	0.275	1.846	0.065

time that the spatial method has been applied to the study of semen quality parameters of infertile men, so as to provide clues for exploring the factors influencing the quality of semen and to provide scientific basis for the local government and the health management department to improve the level of male reproductive health of Wenzhou City at the regional level, as well as to provide a reliable reference for the prevention and control of infertile men in other regions.

The demographic characteristics analysis found that the infertile population in Wenzhou City from 2010 to 2018 was dominated by workers and men with a high school education or less, which is consistent with previous studies [5, 19, 20]. Wenzhou, as the "shoe capital of China," has established many shoe factories. Therefore, compared to other occupations, the proportion of workers in the shoe factories in Wenzhou accounts for the majority of workers in Wenzhou. In addition, these workers are more likely to be exposed to hazardous substances that harm male reproductive health, such as benzene and fluoride, than other occupations [21–23]. In addition, factories in the manufacturing sector have many large heat producing machines, which lead to relatively high exposure temperatures for workers. An animal model study found that high temperatures can induce the production of excessive amounts of endogenous reactive oxygen species, which can damage the DNA integrity of sperm cells and ultimately reduce semen quality [24]. However, these possible causes of occupational exposure still need further research. In the analysis of semen quality parameters, we found that only the mean value of normal sperm forms was lower than the WHO standard, suggesting that lower normal sperm forms may be the main cause for men in Wenzhou City. Therefore, health authorities need to focus on investigating possible causes of lower normal sperm forms, such as benzene exposure, high temperature exposure, and ionizing radiation [21, 23, 25].

Because technicians strictly implement laboratory quality control and the instruments for semen quality parameter analysis remain unchanged, the time-varying trend of semen quality parameters cannot be attributed to laboratory technology or laboratory technicians. From 2010 to 2018, the annual average of total sperm number and semen volume of infertile men in Wenzhou showed a linear increase trend, which was similar to our previous research results [20]. The possible reason was related to the environmental improvement after the implementation of environmental improvement policies and measures in Wenzhou and the improvement of male accessory gland function in Wenzhou. However, the annual average of total sperm motility showed a linear decreasing trend, and the reasons were very complex, which may include occupational exposure, increased stress, poor lifestyle, or a combination of these factors. However, these explanations require further investigation. In addition, this is inconsistent with our previous research results, which showed a linear increase in sperm motility [20]. The reasons for this difference may be: (1) the different screening criteria of the subjects and (2) different research periods. It is worth noting that although there is no linear trend in the annual average of normal sperm forms, it has gradually decreased in recent years. Combined with the analysis results of our semen quality parameters, the normal sperm forms must be more worthy of attention by the relevant health departments. In the spatial analysis of semen quality parameters, our results found that the global autocorrelation of semen quality parameters was not statistically significant and inconsistent with the results of LISA analyses, and these results suggest that semen quality parameters may not be spatially distributed in a certain way. However, the results of cold and hot spot analyses showed that the cold spot areas for progressive sperm motility, total sperm motility, and normal sperm forms were mainly in the main urban areas of Wenzhou (Lucheng District, Ouhai District, Longwan District, and Dongtou District), and the hot spot areas were mainly in the nonmain urban areas of Wenzhou (mainly including Taishun County, Pingyang County, and Wencheng County). One possible reason for this is that there are more shoe factories in the main city than in the nonmain city, and the potential for occupational exposure of patients is greater. Another possible reason is that the pace of life in the main urban areas is faster than in the nonmain urban areas, which leads to a change in the patients' habits and an increase in stress, which are also factors that affect semen quality parameters in men [26, 27]. Therefore, health-related authorities need to focus on investigating and preventing factors that may affect semen quality parameters in the main city of Wenzhou. In addition, we found that the hot spot areas for total sperm count and semen volume were mainly in Dongtou District, which may be related to the geographical location of Dongtou District. Dongtou District, located in the southeast coast of Zhejiang Province and the estuary of Oujiang River, is one of the 14 island counties (districts) in China and consists of 103 islands and 259 reefs. Therefore, the Dongtou area has a vast marine space and rich seafood products. Compared with other regions, Dongtou District is more exposed to a wider area of the sea, so men in Dongtou District are more likely to consume seafood. Seafood is rich in elements such as zinc and selenium, and a review showed that zinc and selenium intake was positively associated with sperm quality [28]. Therefore, the total sperm number and semen volume in Dongtou District, Wenzhou City are high relative to other regions, but further research is needed.

The results of our study are of great significance in guiding the improvement of male reproductive health in Wenzhou City. First, the infertile population in Wenzhou were mainly workers, which suggest that the relevant health departments in Wenzhou should focus on the workers' population in the prevention and control, as well as the

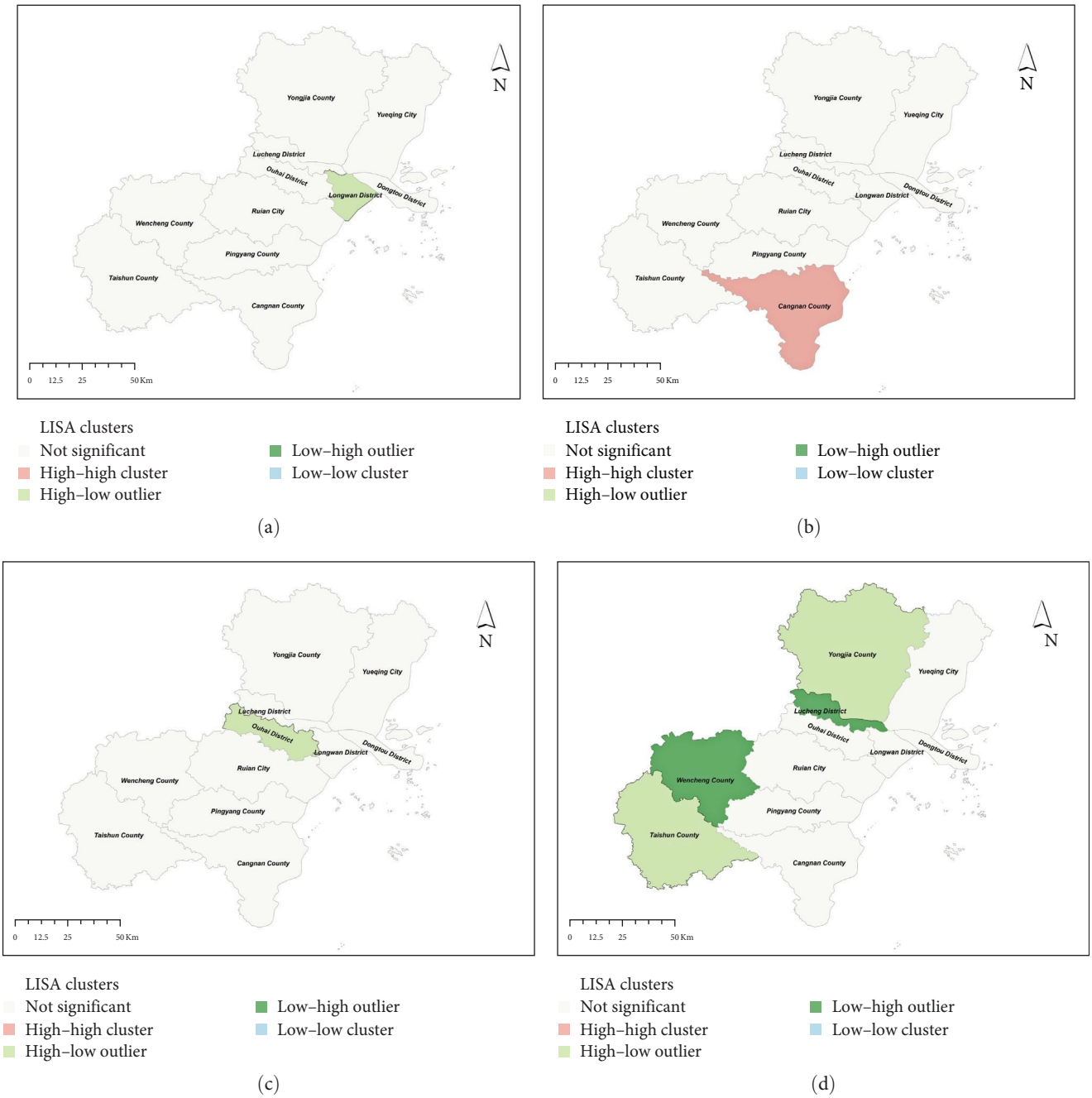
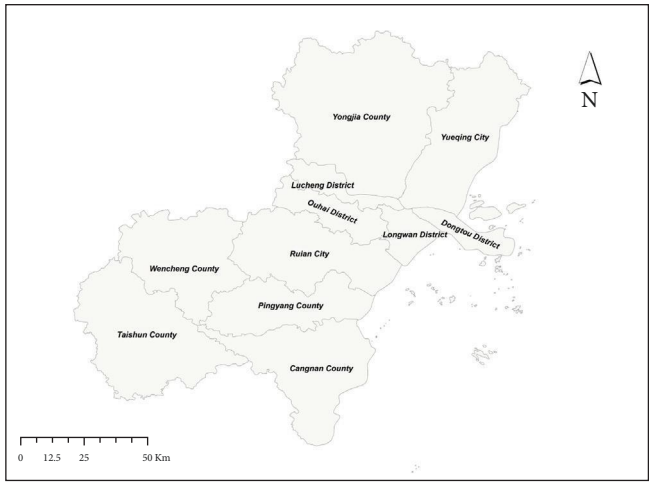


Figure 3: Continued.



(e)

FIGURE 3: Local indicators of spatial association (LISA) cluster maps for the mean value of five semen quality parameters in infertile males in Wenzhou, 2010–2018. LISA spatial cluster map shows the center of the cluster in color. H-H indicates a statistically significant cluster of high each of mean value of five semen quality parameters, H-L represents high each of mean value of five semen quality parameters surrounded with low each of mean value of five semen quality parameters, L-H represents low each of mean value of five semen quality parameters surrounded with high each of mean value of five semen quality parameters, and L-L indicates a statistically significant cluster of low each of mean value of five semen quality parameters. The base layer of the map was obtained from Resource and Environment Science and Data Center (https://www.resdc.cn/Datalist1.aspx?FieldTyepID=7,1). (a) Progressive sperm motility. (b) Total sperm motility. (c) Total sperm number. (d) Semen volume. (e) Normal sperm forms.

investigation and control of their possible risk exposure factors. Second, among the five semen quality parameters, only the normal sperm forms were lower than the WHO standard and have been gradually decreasing in recent years. This suggests that reduced normal sperm morphology may be the main cause of infertility among men in Wenzhou and may continue to worsen in the future. Therefore, health authorities in Wenzhou City should focus on investigating and controlling the factors that may contribute to the low normal sperm forms. Meanwhile, total sperm motility showed a linear decrease, a semen parameter that also deserves the attention of the health authorities. In addition, there was a linear increase in total sperm number and semen volume, which may be related to the improvement of environmental quality. Therefore, it is necessary for health authorities to continue to improve the quality of the environment and, in the future, to pay more attention and to improve the occupational environment. Finally, we found that the cold spot areas for progressive sperm motility, total sperm motility, and normal sperm forms were mainly in the main urban area of Wenzhou City, and the hot spot areas were mainly in the nonmain urban area of Wenzhou City, which suggests that the health-related departments need to focus on investigating, preventing, and controlling the factors that may affect the semen quality parameters in the main urban area of Wenzhou City, including occupational stress and occupational exposure. However, the hot spots for total sperm count and semen volume were mainly in Dongtou District, which may be related to the patients' intake of seafood, so the health-related departments should further investigate and actively promote the intake of elements such as zinc and selenium to improve male reproductive health.

Our study applied spatial methods to the analysis of male semen quality for the first time. By analyzing the spatial characteristics and temporal trends of semen quality in different counties and districts of Wenzhou City, this study can provide clues for exploring the factors affecting semen quality, as well as a scientific basis for the local government and health administration to carry out the of male improvement work in the region. This will provide a scientific basis for exploring the factors affecting semen quality and for local governments and health management departments to improve male reproductive health in study area. Meanwhile, the biggest shortcoming of this study is the lack of data to further explore the factors affecting semen quality, including occupational exposure, stress, and seafood intake, etc., thus failing to provide a stronger basis for the improvement of reproductive health. However, the purpose of this study is to provide clues for exploring the factors affecting semen quality, to provide a scientific basis for the local government and health administration to improve male reproductive health in Wenzhou City regionally, and to provide a reference for the prevention and control of infertile men in other regions. In the future, we will further study the influencing factors of semen quality parameters, especially environmental exposure factors. In addition, this study was conducted on an infertile

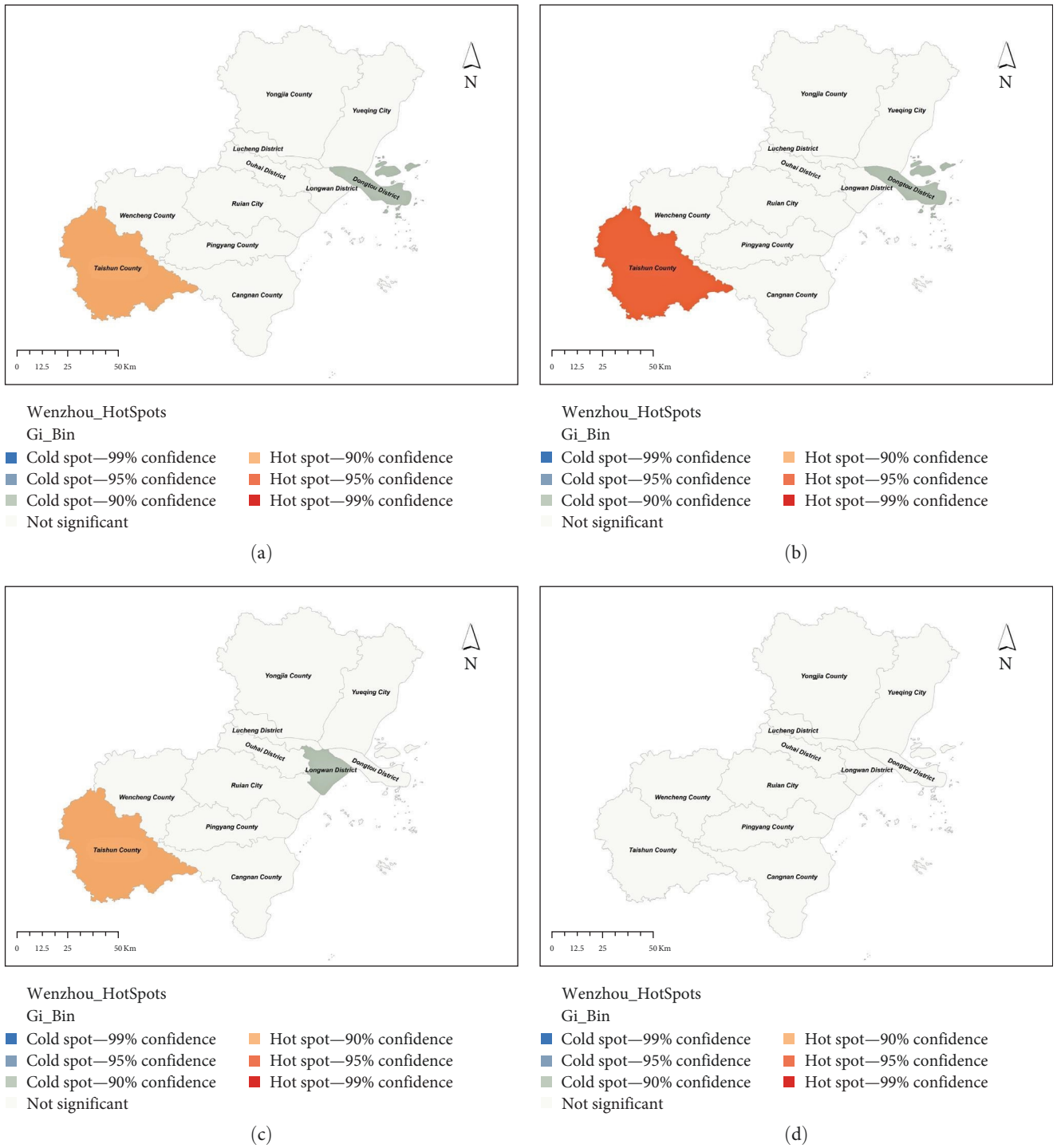
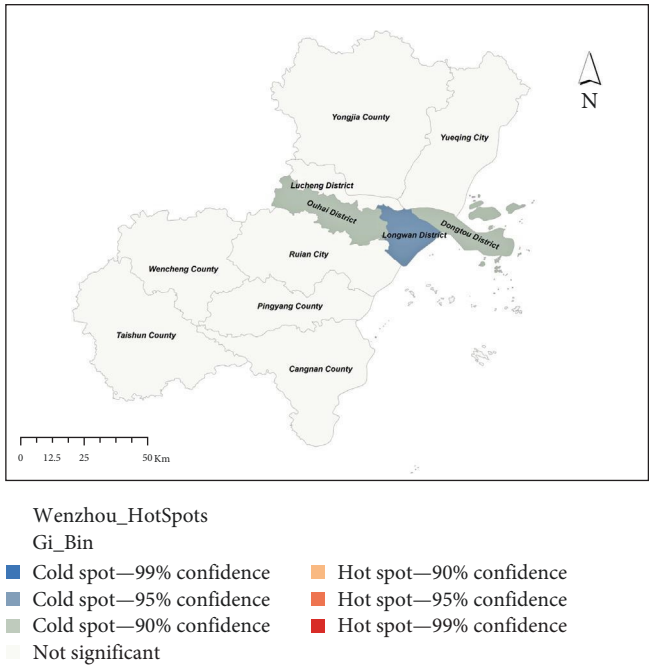


Figure 4: Continued.



(e)

Figure 4: Cold/hot spot analysis maps for the mean value of five semen quality parameters in infertile males in Wenzhou, 2010–2018. The base layer of the map was obtained from Resource and Environment Science and Data Center (https://www.resdc.cn/Datalist1.aspx?FieldTyepID=7,1). (a) Progressive sperm motility. (b) Total sperm motility. (c) Total sperm number. (d) Semen volume. (e) Normal sperm forms.

population, and there was selection bias. Therefore, we need to cautiously extend the results to the general population. In future research, in addition to data from reproductive health centers, we will also include data from other sources, such as physical examination data, sperm bank data, etc., to expand coverage and increase representativeness.

5. Conclusions

The main urban area of Wenzhou is the main cold spot area for progressive sperm motility, total sperm motility, and normal sperm forms, and the mean value of total sperm motility is showing linear decreasing trends. The main urban area is the "harder-hit area" of semen quality, and the government departments need to pay more attention to improve male reproductive health in the main urban area and actively control the potential influencing factors of male reproductive health, such as occupational exposure and life stress. The Dongtou (island) District is the main hot spot analyses of total sperm number and semen volume, and the mean values of total sperm number and semen volume are showing linear increasing trends. The islands area is the "high-withdrawal area" of semen quality, which might be benefited from good environmental quality and plenty of seafood intake.

Data Availability

The data that support the findings of this study are available from the corresponding author (Zhigang Wu) upon reasonable request.

Conflicts of Interest

All authors declare no conflicts of interest.

Acknowledgments

This study was supported by the Education Project of Zhejiang Province (No. Y202146906).

Supplementary Materials

Supplementary 1: Spatial autocorrelation analysis. Table S1: global spatial autocorrelation analysis of progressive sperm motility of infertile men in Wenzhou during 2009–2018. Table S2: global spatial autocorrelation analysis of total sperm motility of infertile men in Wenzhou during 2009–2018. Table S3: global spatial autocorrelation analysis of total sperm number of infertile men in Wenzhou during 2009–2018. Table S4: global spatial autocorrelation analysis of semen volume of infertile men in Wenzhou during 2009–2018. Table S5: global spatial autocorrelation analysis of normal sperm forms of infertile men in Wenzhou during 2009–2018. Figure S1: yearly local indicators of spatial association (LISA) cluster maps for progressive sperm motility in Wenzhou, 2010–2018. Figure S2: yearly local indicators of spatial association (LISA) cluster maps for total sperm motility in Wenzhou, 2010–2018. Figure S3: yearly local indicators of spatial association (LISA) cluster maps for total sperm number in Wenzhou, 2010–2018. Figure S4: yearly local indicators of spatial association (LISA) cluster maps for semen volume in Wenzhou, 2010–2018. Figure S5: yearly local indicators of spatial association (LISA) cluster maps

for normal sperm forms in Wenzhou, 2010–2018. Figure S6: yearly cold/hot spot analysis maps for progressive sperm motility in Wenzhou, 2010–2018. Figure S7: yearly cold/hot spot analysis maps for total sperm motility in Wenzhou, 2010–2018. Figure S8: yYearly cold/hot spot analysis maps for total sperm number in Wenzhou, 2010–2018. Figure S9: yearly cold/hot spot analysis maps for semen volume in Wenzhou, 2010–2018. Figure S10: yearly cold/hot spot analysis maps for normal sperm forms in Wenzhou, 2010–2018. (*Supplementary Materials*)

References

[1] G. M. Centola, A. Blanchard, J. Demick, S. Li, and M. L. Eisenberg, "Decline in sperm count and motility in young adult men from 2003 to 2013: observations from a U.S. sperm bank," *Andrology*, vol. 4, no. 2, pp. 270–276, 2016.

[2] C. Huang, B. Li, K. Xu et al., "Decline in semen quality among 30,636 young Chinese men from 2001 to 2015," *Fertility and Sterility*, vol. 107, no. 1, pp. 83–88.e2, 2017.

[3] H. Levine, N. Jørgensen, A. Martino-Andrade et al., "Temporal trends in sperm count: a systematic review and meta-regression analysis," *Human Reproduction Update*, vol. 23, no. 6, pp. 646–659, 2017.

[4] L. Rosa-Villagrán, N. Barrera, J. Montes, C. Riso, and R. Sapiro, "Decline of semen quality over the last 30 years in uruguay," *Basic and Clinical Andrology*, vol. 31, no. 1, Article ID 8, 2021.

[5] Z.-G. Wu, W.-K. Chen, Q.-J. Fei et al., "Analysis of semen quality of 38 905 infertile male patients during 2008–2016 in Wenzhou, China," *Asian Journal of Andrology*, vol. 23, no. 3, pp. 314–318, 2021.

[6] E. Garcia-Grau, J. Lleberia, L. Costa et al., "Decline of sperm quality over the last two decades in the south of Europe: a retrospective study in infertile patients," *Biology*, vol. 12, no. 1, p. 70, 2022.

[7] N. Jørgensen, A. G. Andersen, F. Eustache et al., "Regional differences in semen quality in Europe," *Human Reprodroduction*, vol. 16, no. 5, pp. 1012–1019, 2001.

[8] S. H. Swan, C. Brazil, E. Z. Drobnis et al., "Geographic differences in semen quality of fertile U.S. males," *Environmental Health Perspectives*, vol. 111, no. 4, pp. 414–420, 2003.

[9] H. Elbardisi, A. Majzoub, S. Al Said et al., "Geographical differences in semen characteristics of 13 892 infertile men," *Arab Journal of Urology*, vol. 16, no. 1, pp. 3–9, 2018.

[10] L. Osadchuk, L. Shantanova, I. Troev, M. Kleshchev, and A. Osadchuk, "Regional and ethnic differences in semen quality and reproductive hormones in Russia: a Siberian population-based cohort study of young men," *Andrology*, vol. 9, no. 5, pp. 1512–1525, 2021.

[11] J. Auger, F. Eustache, C. Chevrier, and B. Jégou, "Spatiotemporal trends in human semen quality," *Nature Reviews Urology*, vol. 19, no. 10, pp. 597–626, 2022.

[12] B. Gu, S. Wang, F. Liu et al., "Same total normal forms sperm counts of males from Lhasa and Shanghai, China," *Environmental Science and Pollution Research*, vol. 29, no. 13, pp. 18820–18831, 2022.

[13] A. Palani, P. Sengupta, A. Agarwal, and R. Henkel, "Geographical differences in semen characteristics: comparing semen parameters of infertile men of the United States and Iraq," *Andrologia*, vol. 52, no. 3, Article ID e13519, 2020.

[14] W. Rodprasert, H. E. Virtanen, S. Sadov et al., "An update on semen quality among young Finnish men and comparison with Danish data," *Andrology*, vol. 7, no. 1, pp. 15–23, 2019.

[15] Q.-C. Zhao, Z. Zhang, L.-M. Zhao et al., "A retrospective cohort study of geographic differences in the semen of 1,012 sperm donors in China," *Translational Andrology and Urology*, vol. 12, no. 2, pp. 187–196, 2023.

[16] M. Zhang, X. Dai, G. Chen et al., "The association between spatial-temporal distribution of prostate cancer and environmental factors in mainland China," *Cancer Epidemiology, Biomarkers & Prevention*, vol. 32, no. 2, pp. 208–216, 2023.

[17] WHO,World Health Organization, *WHO Laboratory Manual for the Examination and Processing of Human Semen*, 5th edition edition, 2010.

[18] X. Dai, G. Chen, M. Zhang et al., "Exposure to ambient particulate matter affects semen quality: a case study in Wenzhou, China," *Andrology*, vol. 11, no. 3, pp. 444–455, 2023.

[19] V. Katukam, M. Kulakarni, R. Syed, K. Alharbi, and J. Naik, "Effect of benzene exposure on fertility of male workers employed in bulk drug industries," *Genetic Testing and Molecular Biomarkers*, vol. 16, no. 6, pp. 592–597, 2012.

[20] X.-C. Dai, M.-Q. Zhang, G. Chen et al., "Will male semen quality improve with environmental quality?" *Asian Journal of Andrology*, vol. 25, no. 2, pp. 252–258, 2023.

[21] F. Marchetti, B. Eskenazi, R. H. Weldon et al., "Occupational exposure to benzene and chromosomal structural aberrations in the sperm of Chinese men," *Environmental Health Perspectives*, vol. 120, no. 2, pp. 229–234, 2012.

[22] S. M. Schrader and K. L. Marlow, "Assessing the reproductive health of men with occupational exposures," *Asian Journal of Andrology*, vol. 16, no. 1, pp. 23–30, 2014.

[23] T. Marić, A. Fučić, and A. Aghayanian, "Environmental and occupational exposures associated with male infertility," *Archives of Industrial Hygiene and Toxicology*, vol. 72, no. 3, pp. 101–113, 2021.

[24] C.-H. Cheng, F.-F. Yang, S.-A. Liao et al., "High temperature induces apoptosis and oxidative stress in pufferfish (*Takifugu obscurus*) blood cells," *Journal of Thermal Biology*, vol. 53, pp. 172–179, 2015.

[25] X. Wang, X. Tian, B. Ye et al., "The association between ambient temperature and sperm quality in Wuhan, China," *Environmental Health*, vol. 19, no. 1, Article ID 44, 2020.

[26] A. L. Gollenberg, F. Liu, C. Brazil et al., "Semen quality in fertile men in relation to psychosocial stress," *Fertility and Sterility*, vol. 93, no. 4, pp. 1104–1111, 2010.

[27] K. Leisegang and S. Dutta, "Do lifestyle practices impede male fertility?" *Andrologia*, vol. 53, no. 1, Article ID e13595, 2021.

[28] A. Salas-Huetos, E. R. James, K. I. Aston, T. G. Jenkins, and D. T. Carrell, "Diet and sperm quality: nutrients, foods and dietary patterns," *Reproductive Biology*, vol. 19, no. 3, pp. 219–224, 2019.