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Government drivers of gastric cancer prevention: The identification of risk areas and macro factors in Gansu, China

Binjie Huang [a,b,c], Feifei Ding [a,b,c], Jie Liu [a,b,c], Yumin Li [a,b,c,*]

[a] Department of General Surgery, Second Hospital of Lanzhou University, Lanzhou, China
[b] Key Laboratory of the Digestive System Tumors of Gansu Province, Lanzhou, China
[c] Lanzhou University, Lanzhou, China

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ABSTRACT

The threat of gastric cancer remains significant worldwide, especially in Gansu, located in northwestern China. However, the spatiotemporal distribution characteristics and the impacts of macro factors such as social-economic, climatic conditions, and healthcare resources allocation were less reported before. Based on the data from the medical big data platform of the Gansu Province Health Commission, Gansu Province Bureau of Statistics and some public databases, we conducted joinpoint regression analysis, spatial autocorrelation analysis, trend surface analysis, space scanning analysis, geographically and temporally weighted regression (GTWR) analysis with Joinpoint_5.0, ArcGIS_10.8, GeoDa, and SaTScan™_10.1.1. Finally, we have found that the increasing trend of gastric cancer incidence in Gansu has reached a turning point and is now declining. Moreover, significant spatial heterogeneity exists in the distribution of gastric cancer across Gansu Province. The identified risk areas and the impacts of macro factors on gastric cancer and their temporal trends could provide evidence for governments to develop specific policies for gastric cancer prevention.

1. Introduction

Gastric cancer ranks fifth and fourth among all malignancies in terms of overall age-standardized incidence (11.1/100,000) and mortality (7.7/100,000), respectively. The highest incidence of gastric cancer is observed in Mongolia (32.5/100,000), closely followed by Japan (31.6/100,000). In China, it holds the fifth position globally with an incidence of 20.6/100,000 (Sung et al., 2021). Gansu Province, situated in the northwestern region of China (Fig. 1), has been identified as having the highest incidence and mortality of gastric cancer in China. Consequently, conducting an epidemiological investigation of gastric cancer within Gansu holds immense significance.

Epidemiological analysis could provide a comprehensive understanding of the cancer epidemic status for residents and governments to develop precise policies for cancer prevention and control. In addition to traditional epidemiology, researchers proposed the spatial epidemiology based on the first and second laws of geography, which is the discipline that involves describing, quantifying, and interpreting changes in the geographic distribution of diseases, particularly with respect to alterations in disease distribution due to environmental exposures over small geographical areas, and the application of spatial epidemiology has been extensive in the fields of urban planning, land use, infectious and oncological diseases research in recent years (Gomes et al., 2021; Aturinde et al., 2019; Lee et al., 2022; Soltani and Askari, 2017).

The research has indicated that various macro factors, including social economic status (SES), living conditions, occupational status, dietary patterns, lifestyle habits, and healthcare resources, can contribute to tumorigenesis through direct or indirect mechanisms. Steven S Coughlin found a positive correlation between SES and prostate cancer incidence, they suggested that poverty, lack of education, immigration status, lack of social support, and social isolation play an important role in prostate cancer stage at diagnosis and survival (Coughlin, 2020), and the similar results were also observed in many cancers, including breast cancer, colorectal cancer, pancreatic cancer and gastric cancer (Baquet and Commiskey, 2000; Coughlin, 2019; Santiago-Rodríguez et al., 2022; Abdel-Rahman, 2020; Gupta et al., 2019). Healthcare resource is another crucial macro factor that impacts cancer screening and treatment, especially in low- and middle-income areas. Individuals with poor SES may choose to remain "silent" rather than seek medical attention due to the inconvenience and financial burden. Furthermore, research has confirmed that climate conditions exerted a significant influence on

* Corresponding author at: Department of General Surgery, Second Hospital of Lanzhou University, Lanzhou, China.
E-mail address: liym@lzu.edu.cn (Y. Li).

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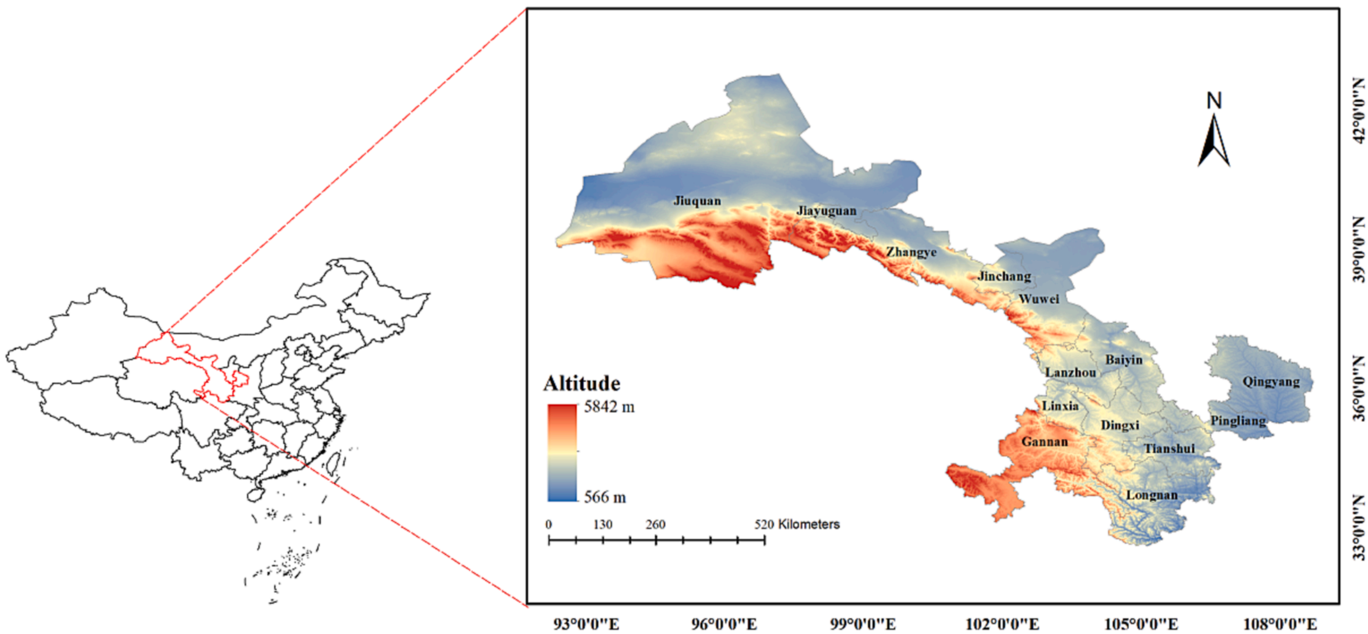

Fig. 1. Map of study area (Gansu Province).

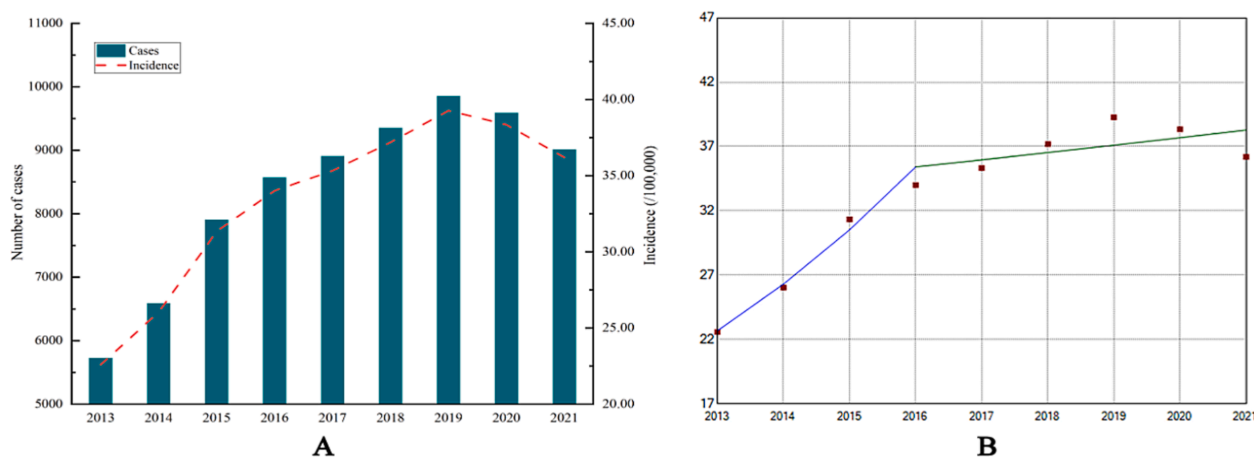

Fig. 2. Time trends of incidences of gastric cancer, Gansu 2013–2021. (A, Cases and Incidence. B, Joinpoint regression.).

the incidence of gastric cancer. However, the specific impacts of these factors and their temporal trends have not yet been reported in Gansu. In this study, we took every county of Gansu as the minimum spatial unit to explore the spatial characteristics of gastric cancer in Gansu with spatial epidemiology, including trend surface analysis, autocorrelation analysis and spatial scanning. In addition, we used geographically and temporally weighted regression (GTWR) model to reveal the correlation between gastric cancer and these macro factors, including GDP per capita, output of the first/second industry, number of medical institutes and beds, regional rainfall as well as ambient temperature.

2. Material and methods

2.1. Data sources

All included patients were new cases in Gansu province according to the International Classification of Diseases criteria, which were downloaded from the medical big data platform of the Gansu Province Health Commission. Demographic, healthcare resource allocation, and economic data from the Gansu Province Bureau of Statistics. Regional rainfall and ambient temperature data were derived from global climatic datasets available at High-resolution gridded datasets.

It should be noted that due to the desensitization process applied to patient data, patients' names and ID numbers have been removed, rendering ethical approval unnecessary. Additionally, demographic data, socioeconomic data, and natural environmental data are all publicly available, so ethical approval is also not required.

2.2. Statistical analysis

We calculated incidence of each county in Gansu and analyzed temporal trends in crude rates of gastric cancer with Joinpoint regression.

In spatial epidemiologic analysis, A trend surface analysis was conducted with incidence data and regional geographic data. Spatial autocorrelation was completed by calculating the global Moran's index and Local Moran's index. In the SaTScan^{TM}_10.1.1 based spatial scanning, we set the county as the minimum spatial unit, 50 % of the total population as the maximum scanning radius, and then we calculated Log Likelihood Ratio (LLR) and its related p value on the basis of the Poisson

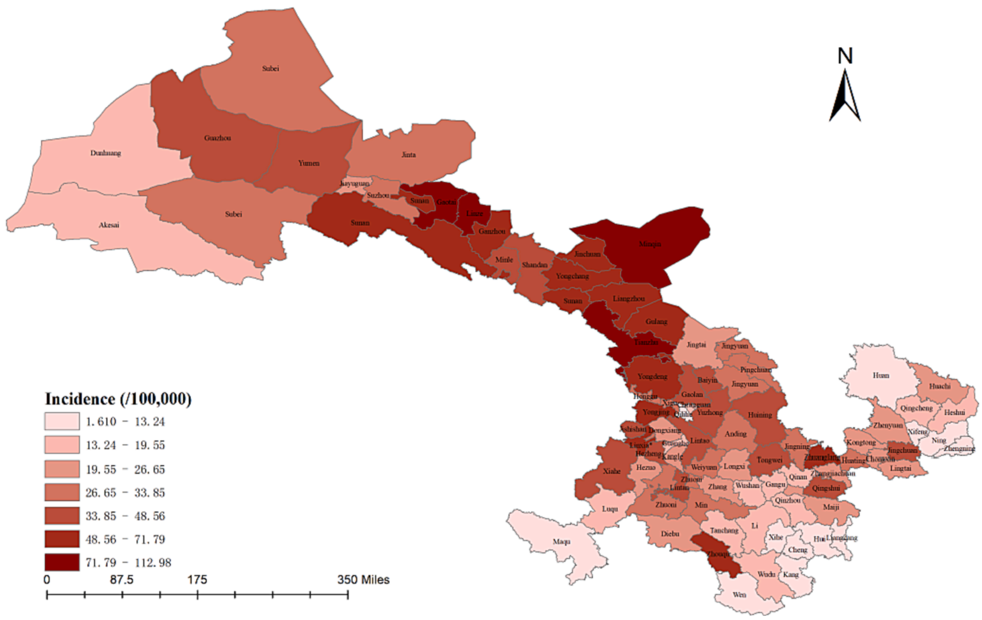

Fig. 3. Map of gastric cancer incidence, Gansu 2013–2021.

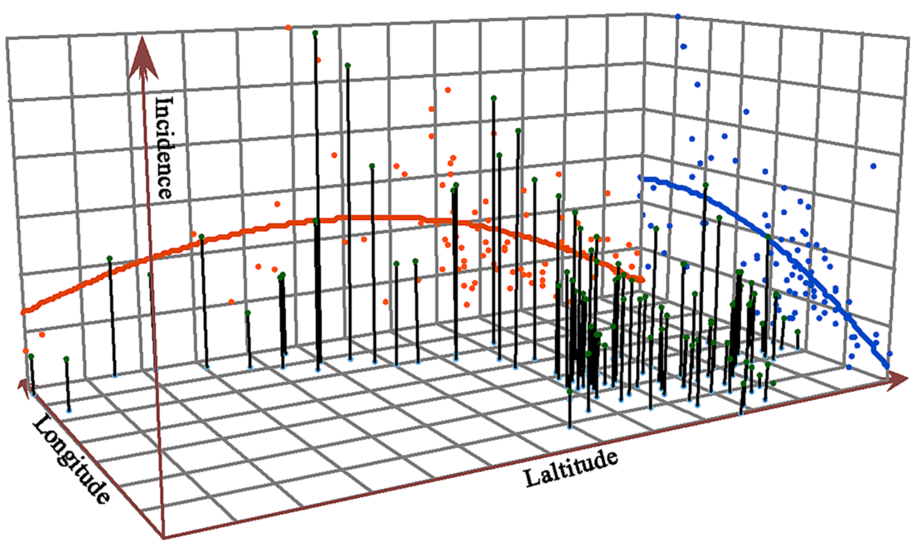

Fig. 4. Trend surface analysis of gastric cancer, Gansu, 2013–2021.

distribution model and Monte Carlo method. Detailed information on how the spatial scan statistic within SaTScan identifies cancer clusters can be found at https://www.satscan.org.

Furthermore, we explored the correlation and spatiotemporal variation between gastric cancer and some macro factors with GTWR model. The formula of GTWR is:

$$y_n = \beta_0(E_i, N_i, T_i) + \sum_{k=1}^{p} \alpha_p(E_i, N_i, T_i) Xi_k + \varepsilon$$

In the formula, y_n represents the gastric cancer incidence in city n, α_p(Ei, Ni, Ti) represents the spatiotemporal coordinates of city i, E_i, N_i represents the projected spatial coordinates, and T_i is the projected temporal coordinates. X_{ik} is the explanatory variable for city i, ε is the random error.

3. Result

3.1. Temporal trend and regional difference of gastric cancer in Gansu

As presented in Fig. 2, a total of 75,522 cases were included in our study, with average cases of 8391 and an incidence of 33.37/100,000. The incidence of gastric cancer in Gansu showed a “rise-fall” change over time (2013–2021). Joinpoint regression analysis revealed a statistically significant increasing trend in the incidence of gastric cancer in Gansu from 2013 to 2019, with an average annual percent change of 6.76 % (95 % CI: 5.05, 9.01; $p < 0.05$). Joinpoint regression analysis revealed two distinct time periods with different annual percent change (APC) values during the study period (segment 1, APC = 16.02; 95 % CI: 10.28, 28.60; $p < 0.05$. segment 2, APC = 1.57; 95 % CI: −2.20, 3.88; $p > 0.05$).

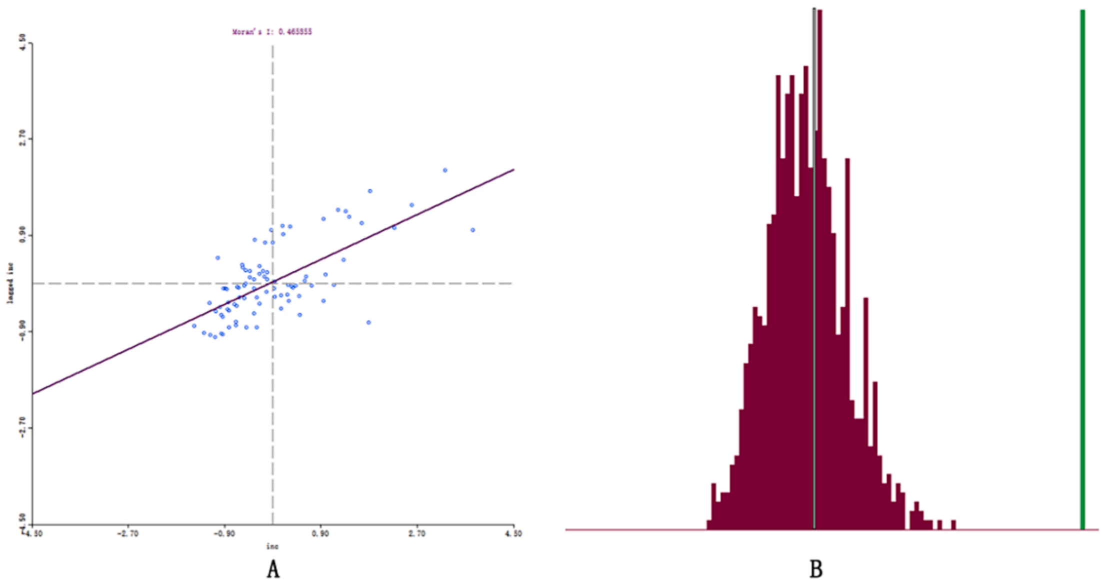

Fig. 5. Global auto-correlation analysis of gastric cancer, Gansu 2013–2021. (A, Moran‘s index scatter plot. B, Permutation test.).

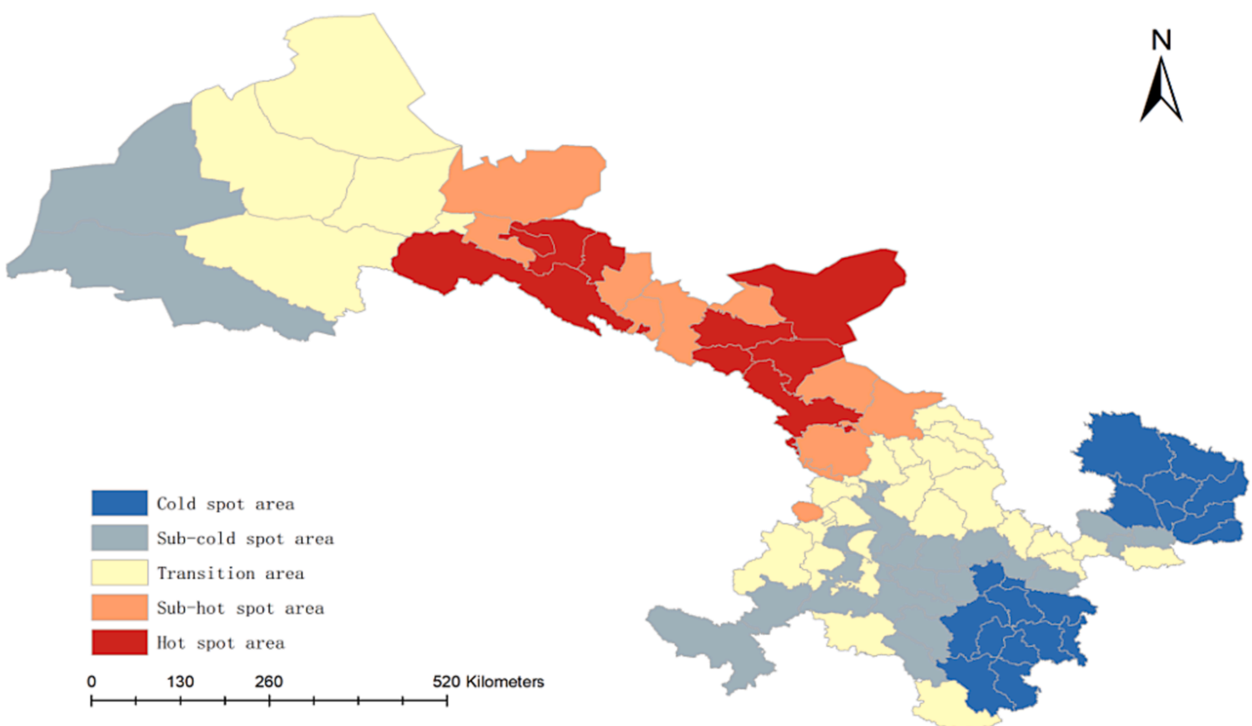

Fig. 6. Hot spot analysis of gastric cancer, Gansu 2013–2021.

We further calculated the gastric cancer incidence of every county and found huge differences in the incidence of gastric cancer among counties in Gansu. As shown in Fig. 3, the top three counties with the highest incidence were Gaotai (112.98/100,000), Linze (101.78/100,000), and Minqin (88.57/100,000); and the last three cities with the lowest incidence were Liangdang (1.61/100,000), Hui (5.36/100,000) and Anning (7.56/100,000).

3.2. *Spatial epidemiologic analysis*

3.2.1. *Trend surface analysis*

We observed a distinct geographical distribution pattern of gastric cancer in all counties of Gansu, with an evident “∩” shape in the east–west direction and higher values concentrated in central Gansu. In the north–south direction, there was a regular decrease, with higher values found in northern Gansu (Fig. 4). All findings suggested the existence of

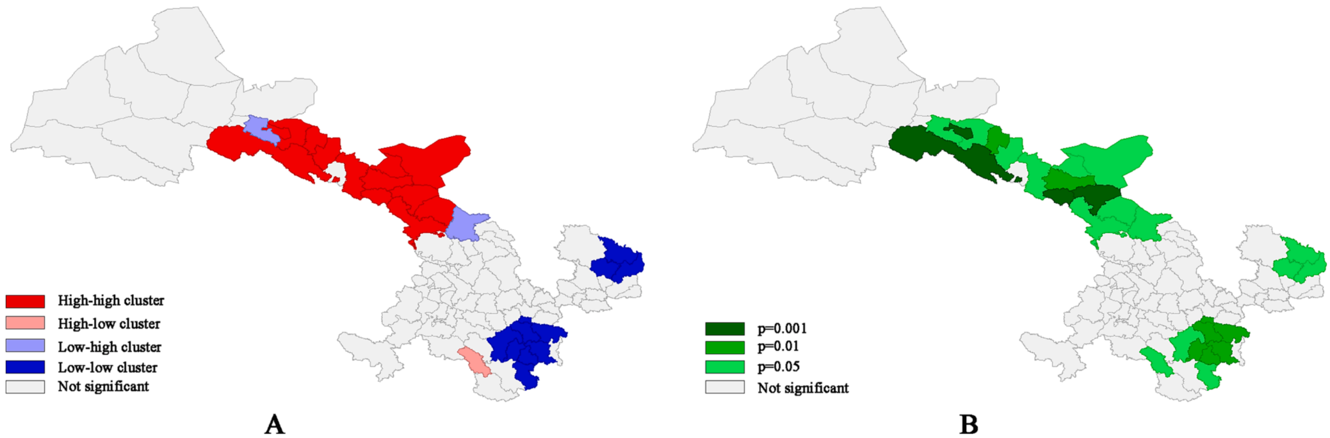

Fig. 7. Local auto-correlation analysis of gastric cancer, Gansu 2013–2021 (A, Clustering map. B, Significance map).

Table 1
Gastric cancer cluster details based on local autocorrelation analysis, Gansu 2013–2021.

Type	Cluster	County	P value
High-high	1	Sunan, Liangzhou	<0.001
	2	Linze, Yongchang	<0.01
	3	Gaotai, Ganzhou, Shandan, Jinchuan, Minqin, Tianzhu, Gulang	<0.05
Low-low	1	Hui, Cheng, Xihe, Qinzhou, Maiji	<0.01
	2	Huachi, Heshui, Qingcheng, Li, Kang	<0.05
High-low	1	Zhouqu	<0.05
Low-high	1	Jingtai, Suzhou	<0.05

significant High-high and Low-low clusters for gastric cancer in Gansu.

3.2.2. The spatial autocorrelation analysis

Spatial autocorrelation analysis revealed a clustered pattern of gastric cancer in Gansu based on the global Moran's index (Moran's index = 0.47, Z = 6.93, $p < 0.05$, Fig. 5). The spatial distribution of gastric cancer in Gansu displayed significant regularity, as revealed by our comprehensive cold-hot spot analysis, the northern region of Gansu represents a central hotspot area with higher incidence, while the southern region is characterized by lower incidence and serves as a leading cold spot area (Fig. 6). Furthermore, we identified the significant cluster areas with different clustering types (Fig. 7, Table 1).

3.2.3. Spatial scanning statistics

The results of the purely spatial analysis form SaTScan™ identified ten high-risk clusters and eleven low-risk clusters, as presented in Table 2 and Fig. 8.

The most likely high risk cluster was identified in the northern region of Gansu, encompassing 16 counties (High risk cluster 1). In this area, there were 23,695 observed cases and 11,165 expected cases, with a statistically significant 156 % increased risk of gastric cancer (RR = 2.56, $p < 0.01$). The first secondary high risk cluster was found in the Hexi region of Gansu (High risk cluster 2), there were a total of 5735 observed cases and 2237 expected cases, with a RR of 2.71 ($p < 0.01$), which implied that there was a 171 % increased risk in this area compared with the total population in Gansu. The most likely low risk cluster was found in the south of Gansu (Low risk cluster 1), a total of 38 counties were included in this area, there were 25,098 observed cases and 34,097 expected cases, with a RR of 0.59, implying that, there is a statistically significant 0.41 % decreased risk of gastric cancer in this area. The RR of another secondary low risk cluster was 0.41 (Low risk cluster 2). The remaining secondary high-risk areas, as well as the low-risk areas are presented in Table 2.

We further complete space–time scanning. As shown in Table 3, the high risk and low risk clusters identified through space–time analysis closely resemble those found in purely spatial clustering.

3.3. Social and natural environmental impact on gastric cancer

Based on the selected explaining variables and explained variables, we fitted Ordinary least squares (OLS) model, Geographically weighted regression (GWR) and GTWR, respectively. According to the results of the goodness-of-fit tests, we chose GTWR as the final model to reveal the correlation between gastric cancer and various macro factors (Table 4, Table 5).

Finally, we found the following conclusions. Firstly, regional rainfall and ambient temperature were protective factors for gastric cancer, they negatively influenced gastric cancer incidence in Gansu. As presented in Fig. 9, the negative impact of regional rainfall on gastric cancer was found to be more pronounced in central Gansu cities but comparatively weaker in other areas, especially inWuwei, Jinchang and Zhangye. Ambient temperature showed stronger negative impact in the southern cities of Gansu, Gannan and Linxia were the two most obviously affected cities. Secondly, healthcare resource allocation positively impact gastric cancer incidence in Gansu. The average coefficient for the number of medical institutions displayed a pattern in which the positive correlation increased from north to south and west to east. Gastric cancer incidence was more influenced by the number of hospital beds per 10,000 people in Hexi region, particularly in Zhangye, its regression coefficients ranged from 0.840 to 1.027 in the highest rank. Thirdly, social economy had different types and degrees of influence on gastric cancer. GDP per capita positively impact gastric cancer in the cities with lower incidence (Longnan, Tianshui, Pingliang, Qingyang, Dingxi and Jiuquan) and negatively influenced the other cities with higher incidence (Zhangye, Jiayuguan, Jinchang, Wuwei, Lanzhou, Baiyin, Linxia and Gannan). The effect of primary industry output on gastric cancer showed a significant north–south difference, the correlation was negative in southern cities and positive in northern cities. Additionally, the impact of the secondary industry's output on gastric cancer was relatively insignificant, with the

Table 2
Gastric cancer cluster details based on purely spatial analysis, Gansu 2013–2021.

Type	Cluster	Cities	Observed cases	Expected cases	RR	P value
High risk	1	Jinchuan, Yongchang, Minqin, Liangzhou, Gulang, Tianzhu, Jingtai, Yongdeng, Honggu, Gaotai, Baiyin, Sunan, Shandan, Minle, Ganzhou, Linze	23695	11665	2.56	<0.01
	2	Linze, Gaotai, Sunan, Ganzhou	5753	2337	2.71	<0.01
	3	Minqin, Jinchuan, Yongchang, Shandan	4523	2235	2.09	<0.01
	4	Gulang, Tianzhu	2829	1263	2.29	<0.01
	5	Honggu, Yongdeng, Yongjing	3084	1790	1.76	<0.01
	6	Jishishan, Yongjing, Linxia, Dongxiang	4075	3012	1.45	<0.01
	7	Jishishan, Linxia	2429	1577	1.56	<0.01
	8	Gaolan, Huining	1765	1253	1.42	<0.01
	9	Subei, Guazhou,Yumen	1144	827	1.39	<0.01
	10	Hezuo, Zhuoni, Lintan, Xiahe, Hezheng	2051	1734	1.19	<0.01
Low risk	1	Huan, Huachi, Qingcheng, Heshui, Zhengning et al.	25089	34097	0.59	<0.01
	2	Chengguan, Qilihe, Anning	2998	6953	0.41	<0.01
	3	Cheng, Li, Xihe, Hui, Kang, Liangdang	1626	4046	0.39	<0.01
	4	Ning, Zhengning, Xifeng, Qingcheng, Heshui	1650	3890	0.41	<0.01
	5	Xigu, Qilihe, Anning	2106	4076	0.50	<0.01
	6	Qinan, Gangu, Wushan	2067	3802	0.53	<0.01
	7	Wen, Wudu	967	2112	0.45	<0.01
	8	Kangle, Guanghe	822	1403	0.58	<0.01
	9	Hasake, Dunhuang	254	551	0.45	<0.01
	10	Maqu, Luqu	128	259	0.49	<0.01
	11	Longxi, Zhang, Weiyuan	2143	2530	0.84	<0.01

largest coefficient being 0.047 (not presented in the Fig. 9).

Furthermore, we found the temporal regularity of the influence caused by these factors to gastric cancer in Gansu. As presented in Fig. 10, the features of influence could be divided into two categories. One is "rise-fall", such as the impact caused by regional rainfall in every city **(a)**, the impact showed a increased trend from period A to period B and a decreased trend from period B to period B. the other one is a steady decreased trend throughout the time period (2013–2021), such as the impact caused by ambient temperature **(b)** in Zhangye, Jiuquan, Jiayuguan, Jinchang and Wuwei. In addition to these shared attributes, specific cities exhibited distinctive traits. Particularly noteworthy is the substantial influence of ambient temperature on Jiuquan, which escalated the risk of gastric cancer between periods A and B but subsequently functioned as a protective factor, effectively mitigating the risk during period B to C.

4. Discussion

The incidence of gastric cancer in Gansu, a region facing economic disadvantages in China, has exhibited an upward trend from 2013 to 2020. However, a declining pattern was observed in 2020, which can be attributed to multiple contributing factors. During the period of 2013–2021, there has been a significant improvement in the economic status of residents in Gansu, with an increase in GDP per capita from 23,647 yuan to 41,046 yuan. Additionally, Gansu has made significant progress in healthcare resources across all cities and states, particularly in economically disadvantaged rural areas where there have been notable increases in both the number of medical technicians and the number of medical institution beds. A well-developed SES can improve the quality of life, dietary patterns and lifestyle of local residents (Fernández-Alvira et al., 2015; Contoyannis and Jones, 2004). Additionally, the increasing accessibility of healthcare resources and health insurance will facilitate local residents in promptly seeking medical attention for any stomach discomfort they may experience, with greater convenience and affordability (Kim et al., 2022).

We have observed a significant disparity in the incidence of gastric cancer among different counties in Gansu. The spatial distribution exhibited an obvious regularity in both north–south and east–west directions, suggesting that there must be significant clustering for gastric cancer in Gansu. Subsequently, we demonstrated statistically significant clustering with spatial autocorrelation analysis and identified specific clustering areas and their related risk (RR) with spatial scanning

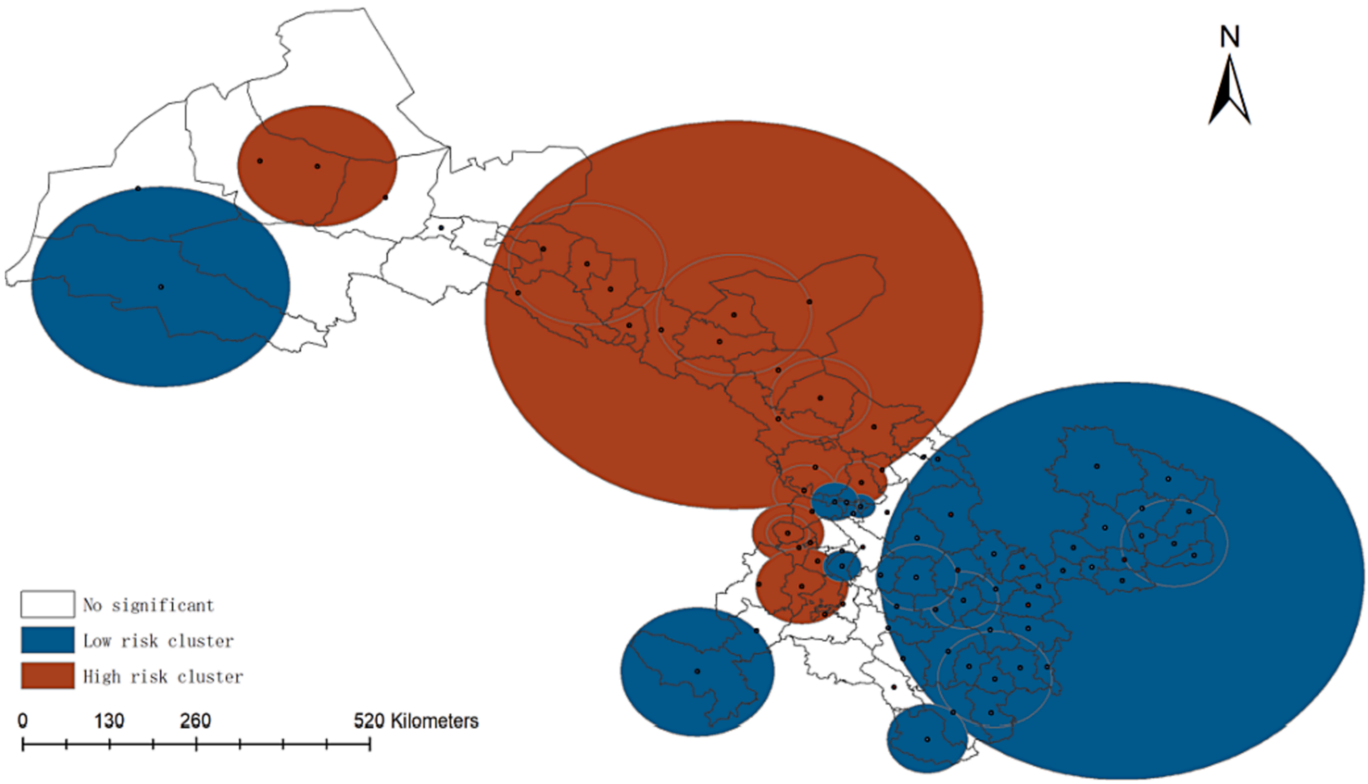

Fig. 8. Purely spatial clusters map of gastric cancer, Gansu 2013–2021.

Table 3
Gastric cancer cluster details based on space–time analysis, Gansu 2013–2021.

Type	Cluster	Years	Cities	Observed cases	Expected cases	RR	p value
High risk	1	2017–2020	Jinchuan, Yongchang, Minqin, Liangzhou, Gulang, Tianzhu, Jingtai, Yongdeng, Honggu, Baiyin, Sunan, Shandan Minle Ganzhou, Linze	11625	5090	2.54	<0.01
	2	2018–2021	Anding, Yuzhong, Huining, Longxi, Lintao, Tongwei	4351	3170	1.40	<0.01
	3	2018–2021	Maqu, Luqu, Xiahe, Hezuo, Zhuoni, Diebu, Lintan, Hezheng, Linxia, Jishishan	2485	1662	1.51	<0.01
Low risk	1	2013–2016	Huan, Huachi, Qingcheng, Heshui, Zhengning et al.	8283	15432	0.47	<0.01
	2	2013–2016	Chengguan, Qilihe, Anning	847	2932	0.29	<0.01
	3	2013	Ganzhou, Minle, Shandan	101	274	0.37	<0.01

Table 4
Performance comparison of different models for gastric cancer, Gansu 2013–2021.

Model	R2	RSS	AICc
OLS	0.657	5947.38	343.22
GWR	0.888	1992.08	335.75
GTWR	0.893	1900.25	342.20

statistics. In comparison to residents in other counties of Gansu, those residing within the most likely high risk and low risk clusters exhibited statistically significant increases and reductions in gastric cancer risk (as listed in Table 2). The spatial characteristics and distinct risk clusters of gastric cancer provide evidence for researchers to investigate the etiological differences between high-risk and low-risk areas, particularly in terms of dietary habits and lifestyles. Additionally, this information can assist governments in implementing health promotion initiatives in high-risk areas, ultimately contributing to the prevention and control of gastric cancer in Gansu.

Precise policies for tumor prevention and control not only effectively

Table 5
The fitting parameters of GTWR model for gastric cancer, Gansu 2013–2021.

Bandwidth	Residual Squares	Sigma	AICc	R^2	R^2 Adjusted	Spatio-temporal Distance Ratio	Trace of SMatrix
0.2762	1900.25	6.7264	342.202	0.8931	0.8710	0.2731	16.3934

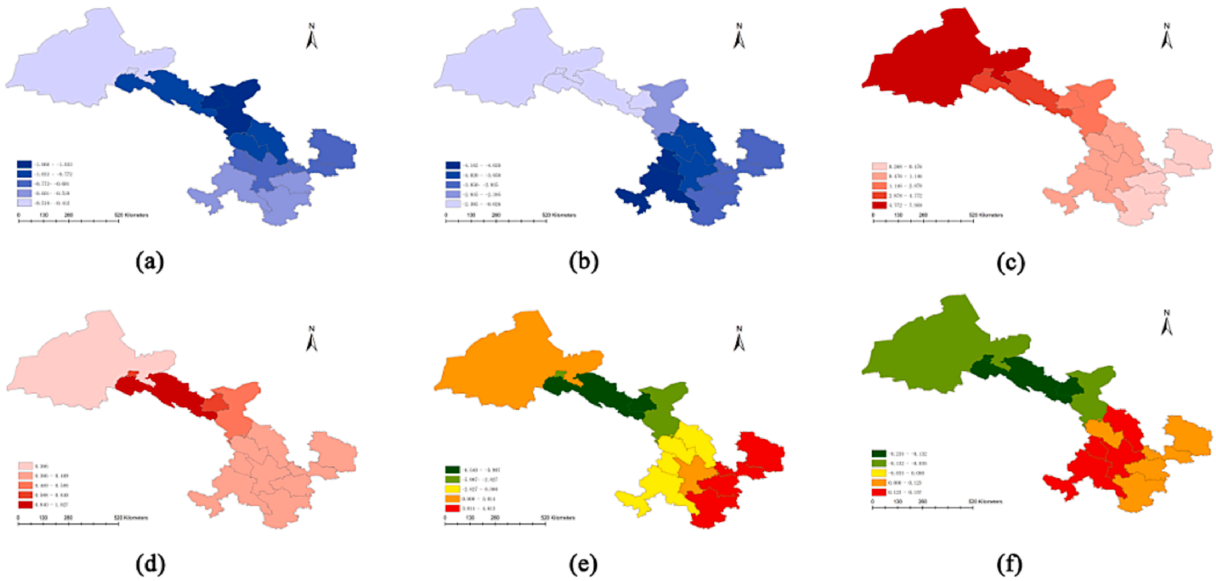

Fig. 9. Spatial distribution of the average coefficients,Gansu 2013–2021. (a-f) represent the spatial distribution of the average coefficients of regional rainfall, ambient temperature, the number of medical institutions per 10,000 people, the number of hospital beds per 10,000 people, GDP per capita and the output value of first industry, respectively.

prevent tumors (Brawley, 2017), but also optimize the allocation of healthcare resources, which is particularly crucial in economically disadvantaged regions. Meanwhile, it is more feasible for governments to take measures in terms of macro factors for gastric cancer prevention, governments should not only continue to promote the development of protective factors, but also strive to mitigate the exacerbation of risk factors over time.

Regional rainfall and temperature serve as protective factors for gastric cancer in Gansu, there exists a close interaction between regional rainfall and temperature. The potential reasons for the impact of precipitation on gastric cancer have been discussed in another study, including regional dietary habits, crop patterns, and SES. Although the impact of regional rainfall on gastric cancer has exhibited a declining trend in recent years, it remains significant in Jinchang, Wuwei, and Zhangye due to their comparatively lower average annual rainfall compared to other cities in Gansu. The scarcity of rainfall consistently impacts drinking water type, dietary habits and regional crop patterns particularly among rural residents who heavily rely on self-cultivated vegetables for nutritional supplementation. Prolonged consumption of pickles and cellar water exposes this population to significant risk factors for gastric cancer, including Nitrites and Helicobacter pylori. Therefore, it is imperative for governments to prioritize the assessment of regional rainfall's impact on Jinchang, Wuwei and Zhangye. Additionally, they should implement comprehensive health promotion strategies in high-risk counties such as Jinchuan, Yongchang, Minqin, Liangzhou, Gulang, Tianzhu, Sunan, Shandan, Gaotai, Minle, Ganzhou and Linze. These strategies should include the establishment of piped water facilities and the cultivation of healthy dietary habits to effectively prevent gastric cancer.

We have also observed a strong correlation between healthcare resources and gastric cancer. While it is likely that healthcare resources impact the diagnosis rate of gastric cancer rather than its occurrence, our results suggest that the influence of healthcare resources allocation on gastric cancer has been decreasing over the past nine years as local diagnostic demands are being met. Nevertheless, there remains room for improvement in optimizing the allocation scheme by reducing saturation in areas (Longnan, Qingyang, Pingliang and Tianshui) with abundant resources and increasing support to those (Jiayuguan, Zhangye, Jinchang and Wuwei) with shortages. Additionally, we observed a more pronounced influence of GDP per capita on gastric cancer compared to the output value of both primary and secondary industries. The impact remained relatively stable but exhibited significant regional variations. The government should continue to promote local economic development in cities such as Zhangye, Jinchang, Wuwei, Jiayuguan et al; whereas in regions with a positive correlation, we need to explore specific mechanisms by which regional economic contributed to gastric cancer in the future.

The present study represents the first extensive population-based investigation aimed at exploring the epidemiological characteristics, high-risk areas, and macro determinants of gastric cancer in Gansu. In comparison to studies relying on data from selected cancer registration sites, our research provides a more objective and accurate results for gastric cancer in Gansu. Meanwhile, there were still some limitations in this study: (1) The gastric cancer incidence for each county in Gansu that we obtained may be slightly underestimated due to the exclusion of patients with incomplete residential address information. (2) The optimal time unit for the GTWR model is annually, however, due to resource constraints, we have opted for a triennial interval. (3) We have discussed the impacts of certain macro factors on gastric cancer, but our analysis is not exhaustive in capturing all aspects of reality. Other crucial macro factors, such as soil composition, air pollution, and population dynamics, were also found as risk factors for cancer. (4) It is imperative to elucidate the specific mechanisms through which regional precipitation, ambient temperature, and regional economy contribute to gastric cancer in the future.

5. Conclusions

The threat of gastric cancer remains significant in Gansu. Fortunately, the increasing trend of gastric cancer incidence has reached a turning point and is now declining. Significant high or low risk clusters with different relative risks exist among counties of Gansu. The identified risk areas, as well as the impacts of macro factors on gastric cancer and their temporal trends, could provide evidence for governments to develop precise policies for gastric cancer prevention.

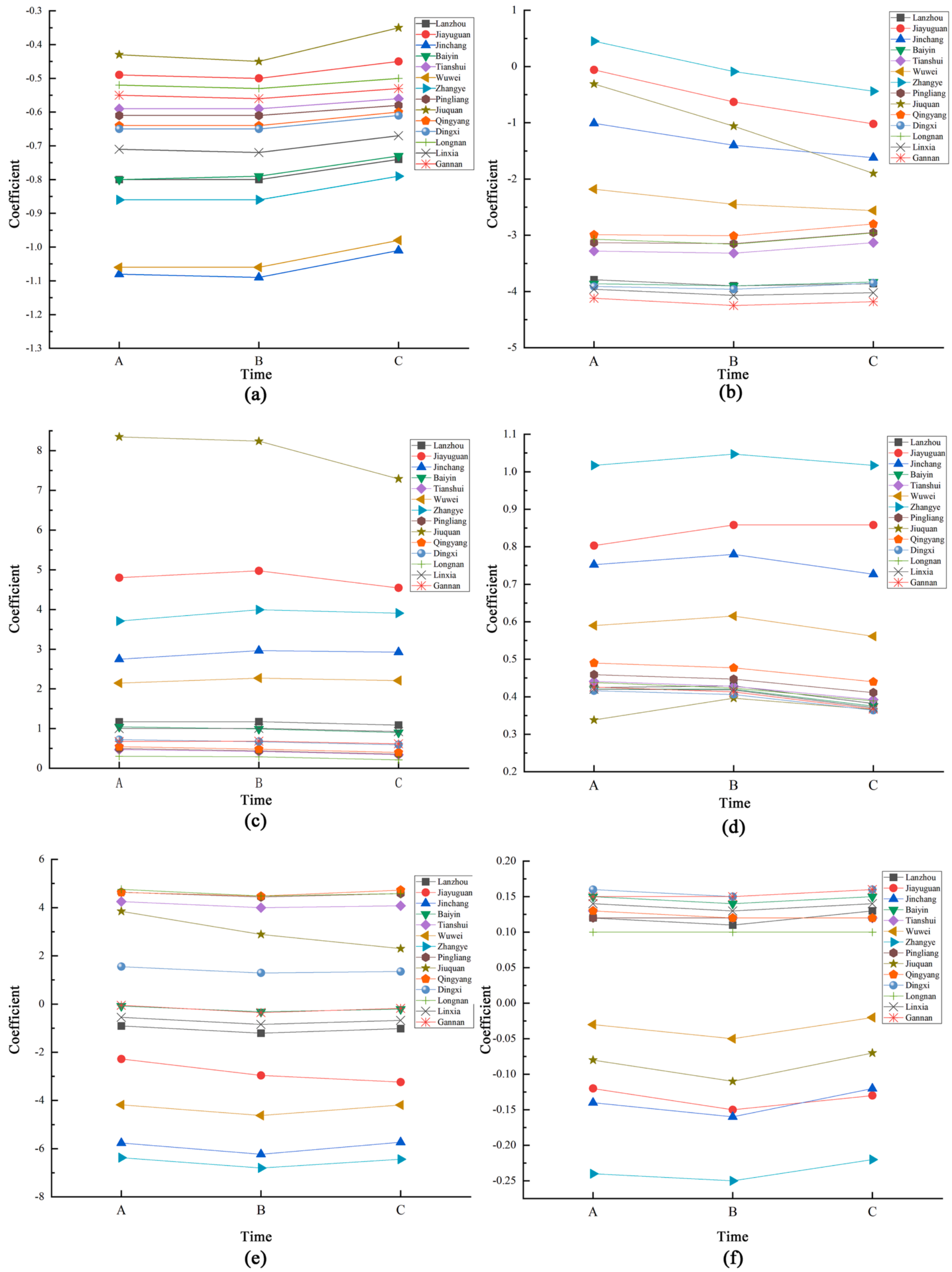

Fig. 10. Temporal variation of estimated coefficients, Gansu 2013–2021. (a-f) represent the coefficient variations of regional rainfall, ambient temperature, the number of medical institutions per 10,000 people, the number of hospital beds per 10,000 people, GDP per capita and the output value of first industry, respectively. (A-C) represent three triennial periods, namely 2013–2015, 2016–2018 and 2019–2021.

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CRediT authorship contribution statement

Binjie Huang: Methodology. **Feifei Ding:** Investigation. **Jie Liu:** Investigation. **Yumin Li:** Conceptualization, Methodology, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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