Preplanned Studies

Characterization of Temporal and Spatial Changes of Endemic Fluorosis Due to Coal-Burning Pollution — China, 2009–2023

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Summary

What is already known about this topic?

Coal-burning pollution type of endemic fluorosis poses a serious health threat to rural inhabitants in certain regions of China.

What is added by this report?

The detection rate of dental fluorosis among children aged 8–12 years in China's coal-burning endemic fluorosis areas showed a significant decreasing trend from 2009 to 2023. Nine provincial-level administrative divisions (PLADs) were classified as low-prevalence clusters, while only Yunnan was identified as a high-prevalence cluster during 2022–2023.

What are the implications for public health practice?

Prevention and control of coal-burning endemic fluorosis should be managed with precision based on the epidemiological characteristics of each PLAD. Efforts should enhance surveillance and early warning systems while strengthening preventive measures in high-risk regions.

ABSTRACT

Introduction: Coal-burning pollution type of endemic fluorosis remains a significant public health threat in certain rural areas of China. This study aimed to analyze the long-term trends in dental fluorosis prevalence in coal-burning fluorosis areas in China from 2009 to 2023.

Methods: We collected and analyzed dental fluorosis detection rates among children aged 8–12 in 12 coal-burning fluorosis provincial-level administrative divisions (PLADs) of China (2009–2023). The optimal Autoregressive Integrated Moving Average with Exogenous Inputs (ARIMAX) time series model was used to predict dental fluorosis detection rates in children from 2019 to 2023. The GeoDa (version 1.20.0; GeoDa Institute) software was employed for spatial analysis, while the SaTScan (version 10.1; GeoDa Institute) was used to analyze spatial-temporal aggregation patterns.

Results: From 2009 to 2023, the dental fluorosis detection rates in children aged 8–12 years showed a decreasing trend, declining from 49.51% to 1.56%. After 2016, achieving the elimination standard ($<$ 15%). There was a goodagreement between the observed detection rates andexpected values, with a relative risk (*RR*) of 0.98. Global analysis shows that the detection rate of dental fluorosis is randomly dispersed. The Moran's I index for dental fluorosis detection rates was positive in 2009, 2011, and 2013, and negative in other years, with *Z*-values ranging from −1.53 to 0.99. Local analysis indicates that Yunnan Province has continuously presented a low-high aggregation pattern from 2011 to 2013. Space-time analysis identified that Yunnan was classified as a high-prevalence cluster in 2022–2023 [odds ratio (*OR*)=1.07, Log likelihood ratio(LLR)=30.45, $P<0.05$].

Conclusions: China has achieved remarkable success in the prevention and control of coal-burning fluorosis. These spatial findings provide critical reference values to support targeted prevention strategies for coal-burning fluorosis.

Coal-burning pollution type of endemic fluorosis, commonly referred to as coal-burning fluorosis, is a chronic fluorosis condition caused by excessive fluoride intake from indoor air and food contaminated by burning high-fluorine coal in open stoves without proper smoke extraction equipment for cooking, heating, and drying food (*1*–*2*). This condition affects more than 31 million people across 12 PLADs in China, representing one of the most significant public health challenges in rural regions (*3*). For nearly five decades, China's coal-burning fluorosis prevention and control program has achieved remarkable results through significant government efforts, primarily involving modifications to cooking stoves and comprehensive health education initiatives (*4*). However, limited information exists regarding the national-level temporal and spatial distribution of this disease in recent years. Therefore, this study aimed to analyze the long-term trends in dental fluorosis prevalence in coal-burning fluorosis areas in China from 2009 to 2023. Our findings reveal a significant decrease in dental fluorosis detection rates among children aged 8–12 years in coal-burning fluorosis areas nationwide. Additionally, 9 provincial-level administrative divisions (PLADs) were classified as low-prevalence clusters, while only Yunnan emerged as a high-prevalence cluster in 2022–2023. These findings provide valuable insights to inform national adjustments to coal-burning fluorosis prevention and control strategies.

The study data were obtained from the Surveillance Report of the Endemic Disease Control Center of the China CDC. The data collected spanned from 2009 to 2023, and focused on the detection rate of dental fluorosis in children aged 8–12 years in the 12 PLADs of China. Eight PLADs, including Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Guizhou, Yunnan, and Shaanxi, had been monitored since 2009; four additional PLADs, including Guangxi, Shanxi, Liaoning, and Henan, were incorporated into the monitoring system beginning in 2019.

Firstly, using the R software (version 4.3.1; R Core Team (2020).R; A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria) with the forecast package, we employed the auto.arima function to model the detection rate of dental fluorosis in children from coal-burning fluorosis areas in China from 2009 to 2018 as the dependent variable, with the qualified rate of improved stoves (Supplementary Table S1, available at http://weekly.chinacdc.cn) as the independent variable, to develop an optimal Autoregressive Integrated Moving Average with Exogenous Inputs (ARIMAX) time series model. This model was used to predict the detection rate of dental fluorosis in children from 2019 to 2023. Secondly, the GeoDa software (version 1.20.0; GeoDa Institute, Tempe, Arizona, United States) was used to conduct spatial analysis of dental fluorosis detection rates in children across each affected area from 2009 to 2023. Both global and local Moran's indices (Moran's I values) were calculated to characterize the geographical clustering patterns of coal-burning fluorosis for each year. Lastly, we analyzed the temporal and spatial patterns of coal-burning fluorosis prevalence for the periods 2009–2018 and 2019–2023 separately, using SaTScan software (version 10.1; GeoDa Institute, Tempe, Arizona, United States) to identify spatial-temporal clusters. Regions of high aggregation were determined by identifying windows with the highest log-likelihood ratio (LLR) and statistical significance (P<0.05).

From 2009 to 2023, the detection rate of dental fluorosis in children aged 8–12 years in coal-burning fluorosis areas showed a consistent decreasing trend, declining from 49.51% to 1.56%. By 2014, the detection rate had fallen below 30%, meeting the control criteria for dental fluorosis in coal-burning fluorosis areas. Further improvement occurred in 2016, when the detection rate dropped below 15%, achieving the elimination standard. There was excellent agreement between the observed detection rates and the expected values from our model, with a relative risk (RR) value of 0.98 (Figure 1).

Global aggregation analysis of dental fluorosis detection rates in children aged 8–12 years in coal-burning fluorosis areas from 2009 to 2023 revealed that the Moran's I index was positive in 2009, 2011, and 2013, while the negative in all other years, Z-values were ranging from −1.53 to 0.99. No statistically significant global spatial autocorrelation was observed for any year (P>0.05), indicating that

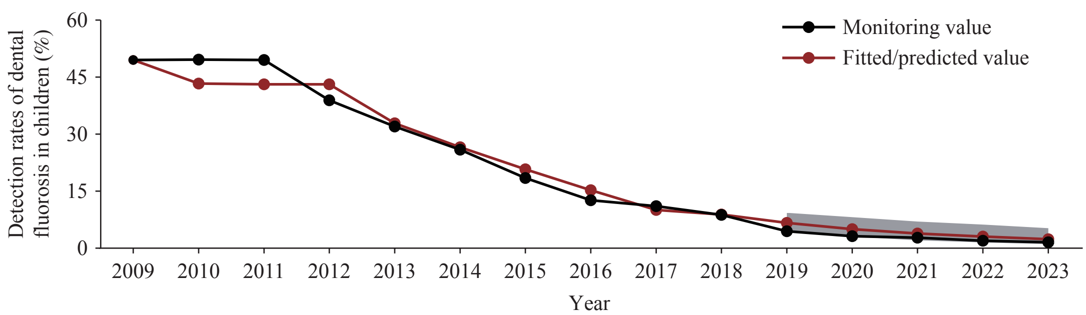

FIGURE 1. Monitoring values and the ARIMAX model predictions of dental fluorosis detection rate in children aged 8–12 years in coal-burning fluorosis areas, China, 2009–2023.
Note: The gray areas are the 95% confidence intervals.

TABLE 1. Global aggregation analysis and local aggregation areas of the dental fluorosis detection rate in children aged 8–12 years in coal-burning fluorosis PLADs, China, 2009–2023.

Year	Global aggregation analysis		
	Moran's I	*Z*	*P*
2009	0.05	0.99	0.18
2010	−0.16	0.05	0.47
2011*	0.03	0.86	0.21
2012*	−0.04	0.55	0.30
2013*	0.04	0.96	0.18
2014	−0.06	0.34	0.33
2015	−0.16	−0.07	0.48
2016	−0.08	0.32	0.35
2017	−0.18	−0.17	0.49
2018	−0.27	−0.63	0.30
2019	−0.16	−0.35	0.40
2020	−0.22	−0.77	0.24
2021	−0.14	−0.31	0.43
2022	−0.35	−1.53	0.06
2023	−0.18	−0.58	0.30

Abbreviation: PLADs=provincial−level administrative division.
* Yunnan shows low−high agglomeration.

dental fluorosis detection rates across the country were randomly dispersed rather than globally clustered. Local aggregation analysis identified a low-high aggregation pattern in Yunnan from 2011 to 2013 (Table 1).

The space-time analysis revealed that the low-prevalence cluster encompassed 9 PLADs, while the high-prevalence cluster involved only 1 PLAD, with these clusters showing alternating patterns across different years. From 2022 to 2023, Yunnan was identified as a high-prevalence cluster (LLR=30.45, P<0.05), with dental fluorosis detection rates exceeding expected values [odds ratio (*OR*) of 1.07]. Interestingly, from 2016 to 2018, Yunnan had been a low-prevalence cluster (LLR=1332.09, P<0.05), with detection rates lower than expected (*OR* of 0.29). Low-prevalence clusters were primarily concentrated in the periods 2015–2018 and 2022–2023. From 2015 to 2018, Hunan, Jiangxi, and Hubei formed a low-prevalence cluster (LLR=1166.73, P<0.05) with an *OR* of 0.39, and these PLADs again became a low-prevalence cluster in 2023 (LLR=800.88, P<0.05), with detection rates lower than expected (*OR* of 0.46). Chongqing exhibited a similar pattern. Additional low-prevalence clusters were observed in Guizhou from 2015 to 2018, and in Shaanxi, Sichuan, and Guangxi from 2022 to 2023, while no prevalence clusters were identified in the remaining PLADs (Table 2).

DISCUSSION

Coal-burning fluorosis in China is distributed across 12 PLADs. Our study found that the detection rate of dental fluorosis in children from coal-burning fluorosis areas varied significantly across time and geographic regions. Notably, Yunnan Province exhibited a low-high aggregation pattern from 2011 to 2013. Currently, 9 PLADs are classified as low-prevalence clusters, while only Yunnan remains a high-prevalence cluster in 2022–2023. These findings reveal the distinct epidemiological characteristics and spatial-temporal distribution patterns of coal-burning fluorosis, providing a scientific foundation for developing targeted regional prevention and control strategies.

From a temporal perspective, the detection rate of dental fluorosis among children aged 8–12 years in affected areas decreased dramatically from 49.51% to 1.56% between 2009 and 2023, falling below the disease elimination standard. This remarkable improvement can be attributed to the Chinese government's substantial commitment to preventing and controlling coal-burning fluorosis. The Central Transfer Payment for Endemic Disease Prevention and Control Project, implemented after 2004, has achieved significant results through continuous disease monitoring, implementation of preventive measures such as improved stoves, promotion of clean energy and healthier lifestyles, encouragement of proper food washing and drying practices, and dissemination of disease prevention knowledge. These comprehensive interventions have effectively blocked the sources and pathways of coal-burning fluorosis exposure, substantially reducing fluorine-related health risks in affected populations (*5*–*6*).

The spatial distribution of dental fluorosis in children from 2009 to 2023 showed a random pattern without global aggregation. To identify specific areas of dental fluorosis prevalence more precisely, we conducted local Moran's I analysis, which revealed that only low-high spatial clusters were present in Yunnan from 2011 to 2013. This pattern reflects the unbalanced distribution of the disease in certain local areas. The regional differences may be attributed to

TABLE 2. Global space-time interaction tests of dental fluorosis detection rate in children aged 8−12 years in coal-burning fluorosis PLADs — China, 2009−2023.

No. of cluster	Time (year)	PLAD	No. of children detected	No. of fluorosis cases detected	Expected cases	*OR*	LLR	*P*
High-prevalence cluster								
1	2022–2023	Yunnan	473,213	14,095	13,226	1.07	30.45	<0.001
Low-prevalence clusters								
2	2015–2018	Guizhou, Chongqing	22,576	2,972	6,671	0.40	1,969.63	<0.001
3	2015–2018	Hunan, Jiangxi, Hubei	12,806	1,578	3,784	0.39	1,166.73	<0.001
1	2016–2018	Yunnan	9,892	883	2,923	0.29	1,332.09	<0.001
1	2022–2023	Shaanxi	178,191	505	4,980	0.10	3,421.70	<0.001
2	2022–2023	Sichuan, Chongqing	334,272	6,811	9,343	0.72	403.62	<0.001
1	2022–2023	Guangxi	20,636	346	576	0.60	55.42	<0.001
3	2023	Hunan, Jiangxi, Hubei	154,099	2,002	4,307	0.46	800.88	<0.001

Abbreviation: PLADs=provincial-level administrative division; *OR*=odds ratio; LLR=log likelihood ratio.

complex geological environments or variations in prevention and control capabilities across different regions (*7*).

The space-time analysis revealed that regions with high and low prevalence clusters appeared in alternating patterns across different years. For example, from 2015 to 2018, Hunan, Jiangxi, and Hubei were identified as low-prevalence clusters and maintained this status in 2023. A similar pattern was observed in Chongqing. Low-prevalence clusters were detected in Guizhou from 2015 to 2018, while Shaanxi, Sichuan, and Guangxi emerged as low-prevalence clusters from 2022 to 2023. No prevalence clusters were observed in other PLADs. The multifactorial determinants of endemic cluster variation operate through two primary mechanisms. Firstly, the operational efficiency of cross-border preventive interventions significantly modulates dental fluorosis transmission dynamics. This is exemplified by the Yunnan province's epidemiological trajectory: initial surveillance data (2016–2018) demonstrated lower prevalence rates (9.53%, 10.59%, 5.58%) relative to the adjacent Sichuan (13.28%, 10.40%, 10.94%) and Guizhou (13.14%, 10.60%, 8.81%) PLADs, meeting the criteria for low-prevalence designation. Subsequent 2022–2023 monitoring revealed a concerning reversal, with Yunnan's rates rising to 2.99% and 2.97%, respectively, exceeding both Sichuan's (2.32%, 1.76%) and Guizhou's (1.85%, 1.30%) contemporaneous values, thereby qualifying for high-prevalence cluster status. Secondly, interprovincial heterogeneity in implementing core interventions (e.g., clean stove adoption rates, health literacy campaigns) and source control of fluoride exposure (water/soil remediation indices) creates divergent epidemiological patterns (*8*–*9*). Nationwide surveillance data (2016–2023) confirm that all PLADs maintain dental fluorosis prevalence below China's 15% threshold for coal-burning-type endemic fluorosis control, though significant geographical disparities persist. This success necessitates evolution from acute-phase interventions to sustainable prevention frameworks, integrating three-tiered governance models with: 1) community fluoride exposure registries, 2) targeted health education for vulnerable subgroups (pregnant women, children under five), and 3) continuous fluoride exposure monitoring, ensuring lasting protection of the achieved public health gains.

This study has several limitations. Since fluorosis symptoms are widespread, affecting multiple systems and organs, with its severity closely related to the fluoride intake amount and the exposure duration, using only dental fluorosis detection rates may underestimate the true extent of fluorosis conditions. Additionally, this study focuses on provincial (municipal) level data. Due to the complexity of geographical environments, internal differences within regions cannot be fully considered. Future analyses at the county (district) level would provide a more precise foundation for developing targeted prevention and control measures.

In summary, an increasing number of PLADs in China have achieved control and elimination of coal-burning fluorosis. Only Yunnan was identified as a high-prevalence dental fluorosis cluster in 2022–2023, highlighting the need to strengthen monitoring in key areas and implement refined regional prevention and control strategies tailored to local conditions.

Additionally, we recommend enhancing the management of improved stoves, consistently implementing health education and awareness campaigns, and increasing public understanding of fluorosis prevention and control. These measures will effectively reduce the risk of endemic fluorosis caused by coal-burning pollution.

Conflicts of interest: No conflicts of interest.

Ethical statement: No ethical approval is required as it was based on public monitoring data without individual patient involvement.

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. Qualification rate of improved stoves in coal-burning fluorosis areas in China, 2009–2023.

Year	Qualification rate of improved stoves (%)
2009	84.41
2010	80.82
2011	83.06
2012	83.00
2013	86.27
2014	89.00
2015	95.71
2016	90.31
2017	90.00
2018	87.53
2019	96.99
2020	99.09
2021	99.62
2022	99.16
2023	99.34