Vital Surveillances

A Comprehensive Analysis and Forecast of Rabies Epidemic and Elimination Challenges — China, 2005–2023

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ABSTRACT

Introduction: The 2030 global target for eliminating dog-mediated human rabies, jointly proposed by the World Health Organization (WHO) and other international organizations, presents significant challenges for China. This study analyzes epidemiological trends (2005–2023), forecasts future case numbers, and compares China's progress with elimination strategies from the United States, Japan, and Brazil to optimize national rabies prevention and control approaches.

Methods: Descriptive statistics were used to analyze the spatiotemporal distribution of human rabies cases across China. The seasonal autoregressive integrated moving average (SARIMA) model was employed to forecast cases for the next two years, with the optimal model selected based on indicators, including the Akaike information criterion.

Results: 24,566 human rabies cases were reported in China from 2005 to 2023. Over these 19 years, rabies prevalence shifted from southeastern to northwestern regions. Provincial trends varied significantly: 14 provincial-level administrative divisions, including Beijing, Tianjin, and Shanghai, achieved zero cases; Shandong, Shanxi, and Chongqing experienced a resurgence; Guangxi, Henan, Hunan, and Anhui maintained high endemic levels; while other regions showed a steady decline. The SARIMA $(0,1,2)(2,1,1)_{12}$ model forecasts 65 cases by 2025, substantially exceeding international case levels during comparable elimination phases.

Conclusions: To achieve the 2030 rabies elimination goal in China, implementing a comprehensive, large-scale dog vaccination strategy is essential within the remaining timeframe.

Rabies is an acute and lethal zoonotic disease that affects the central nervous system of all warm-blooded animals (*1*). The primary transmission route is from infected canines to humans, with nearly 100% mortality once clinical symptoms appear (*2*). Currently, human rabies causes an estimated 59,000 deaths annually across more than 150 countries, predominantly in low and middle-income regions of Asia and Africa (*3*). In 2015, the World Health Organization and other international organizations established a global target to eliminate dog-mediated human rabies by 2030 (*4*). Several regions have already achieved this goal, including Western Europe, Canada, the USA, Japan, and 28 Latin American countries. Various Asian and African countries have made significant progress in reducing human rabies cases (*5*). In China, human rabies caused over 1,000 deaths annually from 2002 to 2004, representing the highest mortality among notifiable communicable diseases during that period (*6*). Since establishing sentinel surveillance in 2005, China has implemented comprehensive control measures, including policies and regulations for rabies prevention, improved surveillance and management systems, and the development of effective vaccines and treatments (*7*). These efforts have resulted in a consistent annual decrease in cases beginning in 2008, demonstrating substantial progress in epidemic control (*8*). Given these favorable prevention and control outcomes, the question of how much further case numbers can decrease in the next two years emerges. This study aims to analyze the epidemiological characteristics and trends of human rabies in China to provide a scientific foundation for implementing and refining rabies control strategies.

METHODS

Data Sources and Collection

Human rabies case data (2005–2023) were retrieved from the National Notifiable Disease Reporting System and provided by the China CDC.

Data Analysis

Microsoft Excel 2021 (Microsoft Corporation, Redmond, WA, USA) was used to organize the human rabies data. Counted data were presented as frequency or component ratio. Categorical data were analyzed using a chi-squared (χ^2) test and a one-way analysis of variance. Implementation of the SARIMA model involved four steps: model identification, parameter estimation, model diagnosis, and model prediction.

All statistical analyses were conducted using R software (https://www.r-project.org/). A P value <0.05 was considered statistically significant. Spatial distribution maps were generated with ArcGIS software (version 10.8; ESRI Inc., Redlands, CA, USA).

Comparison of Cases Among Countries

Rabies case data from 5, 10, and 15 years preceding elimination in three countries (USA, Japan, and Brazil) were compared with projected cases in China.

RESULTS

Overall Epidemic Trend

24,566 human rabies cases were reported in China from 2005 to 2023, with an annual average of 1,293 cases and an incidence rate of 0.096 cases per 100,000 persons. Since peaking in 2008, cases have steadily decreased to only 120 in 2023, the lowest level recorded since 1951 (Figure 1A). The geographic scope of the epidemic has also contracted significantly, with affected provincial-level administrative divisions (PLADs) fluctuating between a maximum of 29 in 2013 and a minimum of 16 in 2022. The number of affected counties decreased dramatically from 997 in 2007 to 101 in 2023, indicating a transition to a sporadic epidemiological pattern.

Regional Distribution

Regional distribution of cumulative cases From 2005 to 2023, human rabies cases were reported in all PLADs of China, with 55.61% (13,660/24,566) of cases occurring in 11 southeastern PLADs (Fujian, Guangdong, Hainan, Jiangxi, Zhejiang, Jiangsu, Shanghai, Guangxi, Hunan, Hubei, and Anhui).

Changes in rabies epidemiology across PLADs The spatial distribution of human rabies from 2005 to 2023 can be divided into three distinct phases: 2005–2007, 2008–2014, and 2015–2023. During 2005–2007, five PLADs (Xizang, Qinghai, Gansu, Ningxia, and Liaoning) reported no cases. In 2008–2014, the number of cases further decreased, with Xizang and Jilin reporting no cases. By 2015–2023, rabies cases were reported throughout the country, with sporadic events occurring in previously rabies-free regions.

Based on changes in the proportion of cases relative to the total number reported, PLADs can be categorized into four zones: no cases, declining epidemic, re-emergent epidemic, and high incidence (top five reported cases) (Table 1). From 2005 to 2023, 14 PLADs achieved zero cases, with Liaoning, Jilin, Heilongjiang, Xinjiang, Qinghai, Xizang, Shanghai, Beijing, and Tianjin, reporting no cases for three or more consecutive years, and Hainan, Fujian, Inner Mongolia, Gansu, and Ningxia for two consecutive years. Shandong (2020), Shanxi (2021), and Chongqing (2020) also achieved zero cases in the past but experienced a case resurgence from 2021 to 2023. Hunan, Henan, Guangxi, and Anhui maintained high prevalence, with Henan showing a significant increase in case proportion, accounting for more than 10% in 2016, and rising to 28.33% in 2023. Cases in Guangxi showed a declining trend, even though the PLAD ranked among the top three for 16 years. Hunan remained among the top three PLADs for 68.42% (13/19) of the study period, ranking first from 2016 to 2022. The percentage of cases in Anhui steadily increased, and the PLAD has consistently ranked in the top four since 2019.

Time Distribution

Human rabies cases occur year-round, with peaks between June and November, typically in August (Supplementary Figure S1, available at https://weekly.chinacdc.cn/). Throughout the 19-year study period, August was the peak month for nine years and October for seven years. On average, August accounted for 10.93% of cases [95% confidence interval (*CI*): 9.34%, 12.52%], while February had the lowest proportion at 5.60% (95% *CI*: 3.01%, 7.19%). The χ^2 test showed no significant difference in monthly rabies incidence across years (P>0.05). Notably, following the peak in 2007 and particularly since 2012, the seasonal pattern has become less pronounced as annual case numbers have continued to decline.

Demographic Features

The incidence of human rabies in China varies by sex, age, and occupation. The overall male-to-female ratio was 2.33:1 (17,196:7,370), with no significant

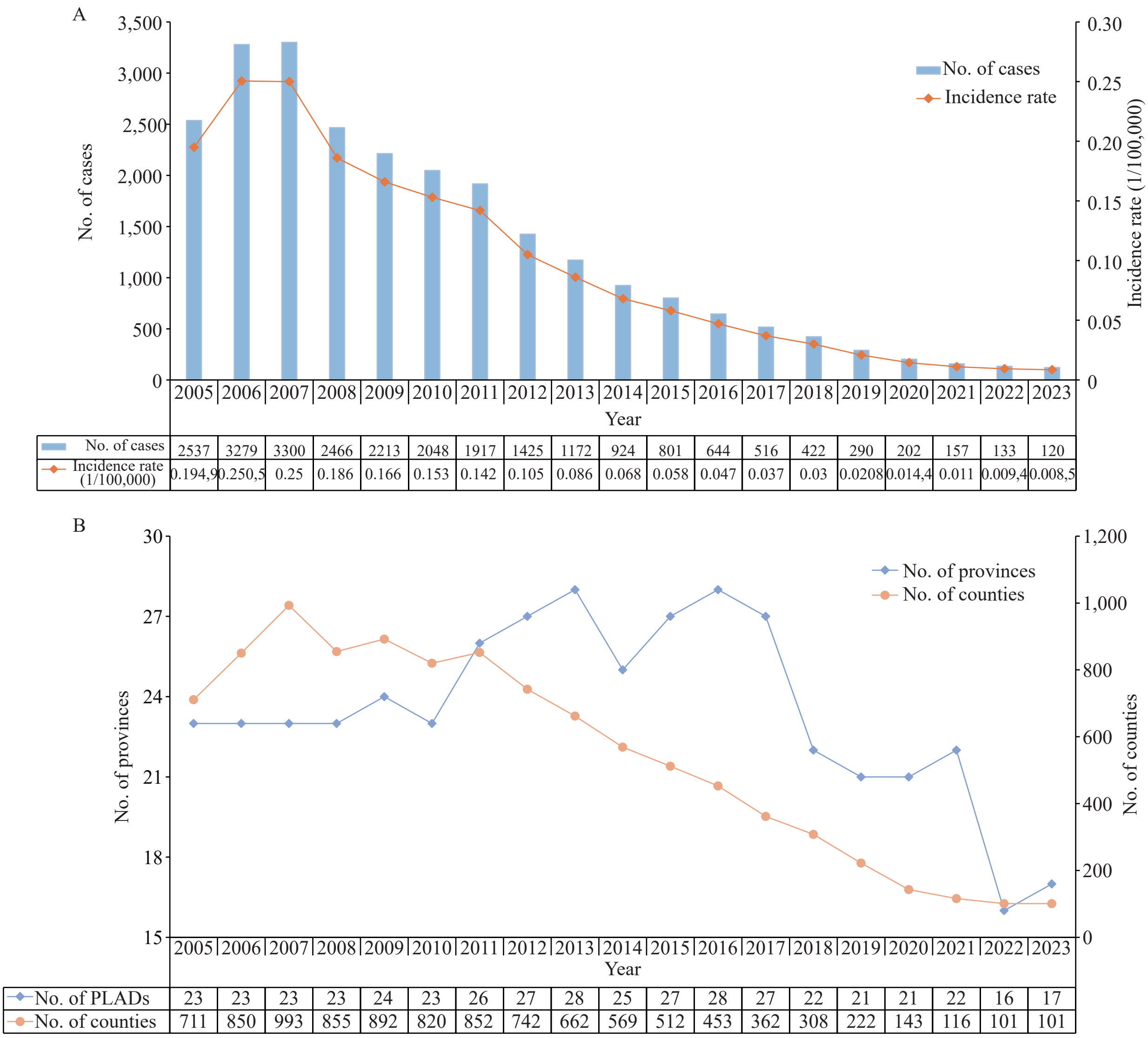

FIGURE 1. Time series analyses of human rabies cases in China, 2005–2023. (A) Annual cases and incidence; (B) Affected areas.
Abbreviation: PLAD=provincial-level administrative division.

TABLE 1. Rabies epidemic in China from 2005 to 2023.

Epidemic zone	Provincial-level administrative divisions	Proportion changes (%)	Counting
No. of cases	Liaoning, Jilin, Heilongjiang, Xinjiang, Qinghai, Xizang, Shanghai, Beijing, Tianjin, Hainan, Fujian, Inner Mongolia, Gansu, Ningxia	0–1.74	14
Decline	Yunnan, Jiangsu, Guangdong, Sichuan, Hebei, Shaanxi, Zhejiang, Guizhou, Jiangxi, Hubei	0.03–19.55	10
Re-emergent	Shandong, Shanxi, Chongqing	0–7.02	3
High Prevalence	Guangxi, Hunan, Henan, Anhui	1.58–31.85	4

annual variation (P>0.05). Significant differences were observed across age groups (P<0.001), with individuals aged 50–60 being the most affected (Supplementary Figure S2A, available at https://weekly.chinacdc.cn/). Statistically significant differences in incidence rates were also observed across occupational groups, with farmers being the most affected (68.4%), followed by students (12.13%) and children (6.46%) (Supplementary Figure S2B).

SARIMA Model Prediction

Using monthly human rabies case data from China (2005–2023), we established and plotted a time series

(Figure 2A). The seasonal-trend decomposition revealed distinct seasonality with peaks from August to October, indicating a nonstationary series (Figure 2B). We applied a log transformation with first-order regular and seasonal differencing (d=1, D=1), which effectively eliminated the seasonal pattern. The augmented Dickey–Fuller (ADF) test confirmed that the differential series was stationary (ADF=−5.9811, P<0.001). The autocorrelation function (ACF) and partial autocorrelation function (PACF) plots suggested parameters p, P, q, and Q should be set between 0 and 2 (Supplementary Figure S3A–B, available at https://weekly.chinacdc.cn/). We selected the SARIMA $(0,1,2)(2,1,1)_{12}$ model based on optimal Akaike information criterion (AIC), Bayesian information criterion (BIC), and log-likelihood values (Supplementary Table S1, available at https://weekly.chinacdc.cn/), which demonstrated statistically significant parameters (Supplementary Table S2, available at https://weekly.chinacdc.cn/). The Ljung–Box test confirmed the residuals were white noise (χ^2=0.331, P=0.565), while the ACF and PACF plots indicated they were random and independent (Supplementary Figure S3C–D).

Our predictions showed a continued decline in rabies cases, with an estimated 83 cases in 2024 and 65 cases in 2025 (Supplementary Table S3, available at https://weekly.chinacdc.cn/). The actual values closely matched the fitted values, with all predictions falling within the 95% *CI*, thereby validating the model's accuracy and reliability (Figure 3). Notably, actual incidence may be influenced by factors such as control measures, changes in public health policies, and unforeseen circumstances, which introduce uncertainties into the predictions.

Comparison of Elimination Progress

Projecting toward the 2030 elimination target, human rabies cases in China are expected to decrease to 65 by 2025. In comparison, the United States eliminated human rabies in 2007, reporting only 2, 3, and 2 cases in the 15, 10, and 5 years preceding elimination, respectively (*9*). Japan achieved elimination in 1956, with fewer than 10 cases reported during both the 5-year and 10-year periods prior to elimination (*10*). Brazil eliminated rabies in 2016, reporting 23, 5, and 2 cases at 15, 10, and 5 years before elimination, respectively (*11*) (Table 2).

DISCUSSION

Rabies remains endemic in China, but significant progress has been made since 2005 due to comprehensive monitoring and control measures (*8*).

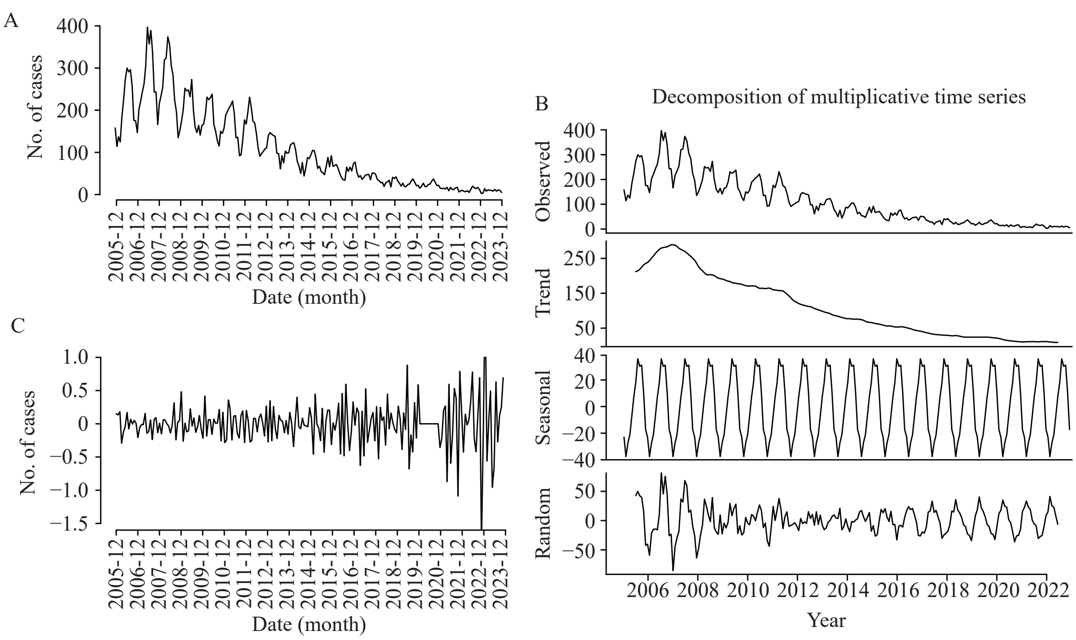

FIGURE 2. Time series of monthly incidence data of human rabies in China from 2005 to 2023. (A) Sequence diagram of the original sequence; (B) Trend, seasonal, and residual components derived from seasonal-trend decomposition of monthly incidence of human rabies; (C) Sequence diagram after natural logarithm transformation and first-step differencing and seasonal differencing with a period of 12 months.

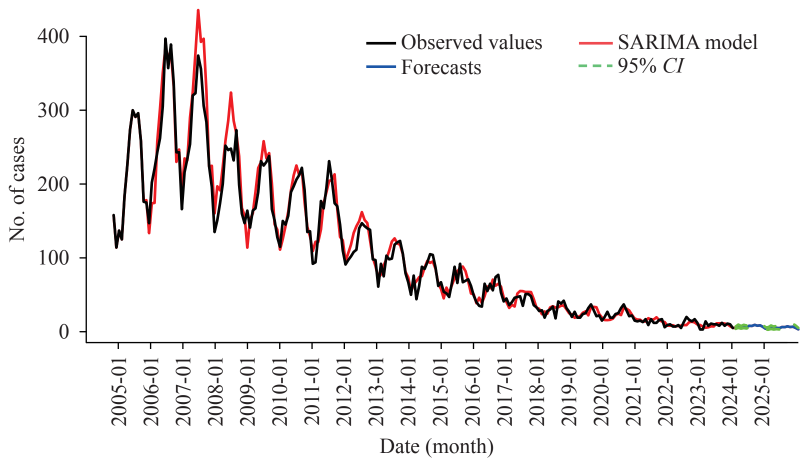

FIGURE 3. SARIMA (0,1,2) $(2,1,1)_{12}$ model fitting, validation, and prediction based on monthly human rabies incidence data in China from January 2005 to December 2023.
Note: The black line represents the actual value, the red line represents the fitting value, and the green line represents the 95% *CI*.
Abbreviation: *CI*=confidence interval.

TABLE 2. Comparison of rabies elimination progress among different countries.

Country	Pre-elimination cases			Elimination year
	15 years	10 years	5 years	
USA	2	3	2	2007
Japan	–	<10	<10	1956
Brazil	23	5	2	2016
China	801	202	65	2030

Note: "–" represents missing data.

Except for an increase from 2005 to 2007, the number of rabies cases has steadily decreased to 120 in 2023, representing a 96.36% reduction from the peak of 3,300 cases in 2007. The number of affected regions reached its lowest point in 2022, a 42.86% reduction from the peak observed in 2013. Annual cases along the southwest and southeast borders have significantly decreased. The proportion of cases in Guizhou dropped from 19.55% in 2006 to 1.67% in 2023, exemplifying effective control in traditional high-incidence areas. Recent policies, including the “National Medium and Long-term Animal Epidemic Prevention Planning (2012–2020),” “National Animal Rabies Prevention and Control Plan (2017–2020),” and “Law of the People’s Republic of China on Animal Epidemic Prevention,” have enhanced animal management and immunization, especially for dogs (*7*). The updated “Interpretation of the National Regulation for the Rabies Exposure Prophylaxis (2023 Edition)” further refined post-exposure procedures to achieve standardization and consistency. These ongoing efforts reflect continued improvement in rabies control across the country.

The prevalence of rabies, a natural zoonotic disease primarily spread by domestic dogs, has declined in China, but previously rabies-free areas remain vulnerable to reintroduction. For example, regions in northeast and western China with historically few outbreaks experienced re-emergence in Liaoning and Ningxia after being rabies-free for six years (2005–2010) and eight years (2003–2010), respectively (*12*). Virus traceability and spatial clustering analyses indicated that the outbreak in Ningxia resulted from pathogens spreading from Inner Mongolia (*13*). The Qinghai–Xizang Plateau, isolated and sparsely populated, remained rabies-free for over a decade but began reporting cases in Qinghai and Xizang in 2012 and 2015, respectively. With cases emerging in Xizang, rabies has now been reported in all PLADs (*12*). Animal hosts can bypass both natural barriers and national borders. In 2017, cases in Shigatse and Nagqu of Xizang were traced to Nepalese strains crossing the border (*14*). These examples highlight that without an immune barrier in host animal populations, eliminating rabies remains unattainable.

As shown in Table 2, rabies cases in China are expected to reach 65 by 2025, which is higher than the case numbers in Japan, the USA, and Brazil, 15 years before their respective elimination dates. Thus, China faces the challenge of achieving in five years what took other countries over 15 years to accomplish. Despite differences in economic development and policy implementation, the successful elimination of rabies in these countries provides valuable lessons for understanding the challenges and urgency of rabies elimination in China. Dog vaccination is a proven and cost-effective strategy (*15*). Drawing from global experiences, the following measures should be adopted for dog management and vaccination efforts in China: 1) establish an authoritative body to coordinate departmental efforts; 2) ensure clear departmental responsibilities, focusing on comprehensive coverage for rural and stray dogs; and 3) conduct phased evaluations of program effectiveness, while continually monitoring dog infection and vaccination rates. Notably, strong policies and decisive implementation are central guarantees for effective prevention and control.

Rabies is a serious infectious disease that threatens public health. After 20 years of prevention and control efforts, rabies transmission in China has shifted from widespread to localized, indicating progress towards elimination. However, rabies will not disappear without concerted action. Strong policies and effective implementation are crucial to establishing robust dog vaccination defenses. Given time constraints and the complexity of the task, the One Health concept must be embraced to eliminate dog-to-human rabies by 2030.

Conflicts of interest: No conflicts of interest.

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Ethical statement: The National Health Commission of the People's Republic of China determined that rabies case collection is integral to public health surveillance and is exempted from institutional review board approval.

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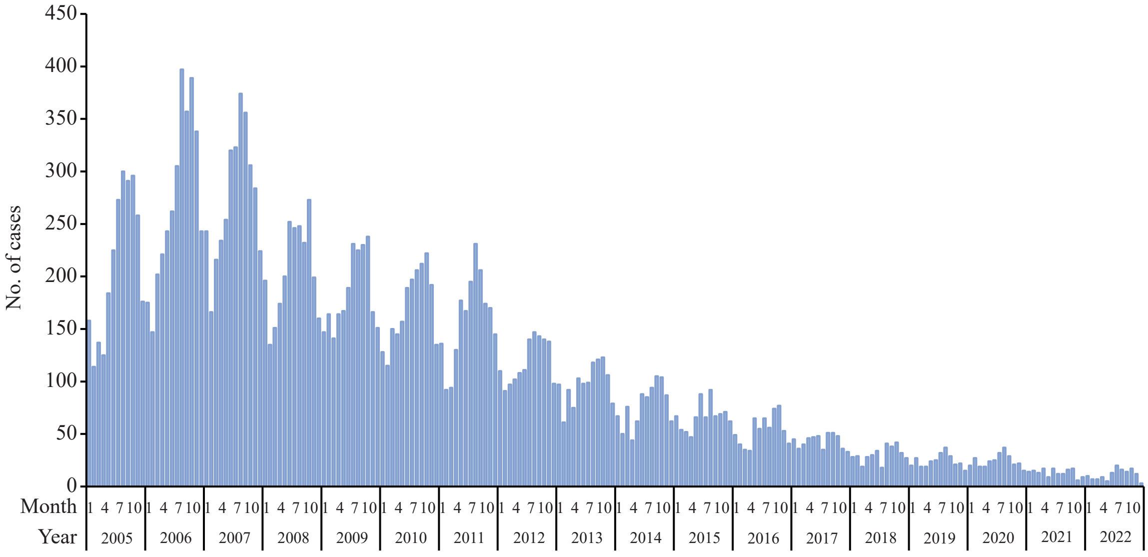
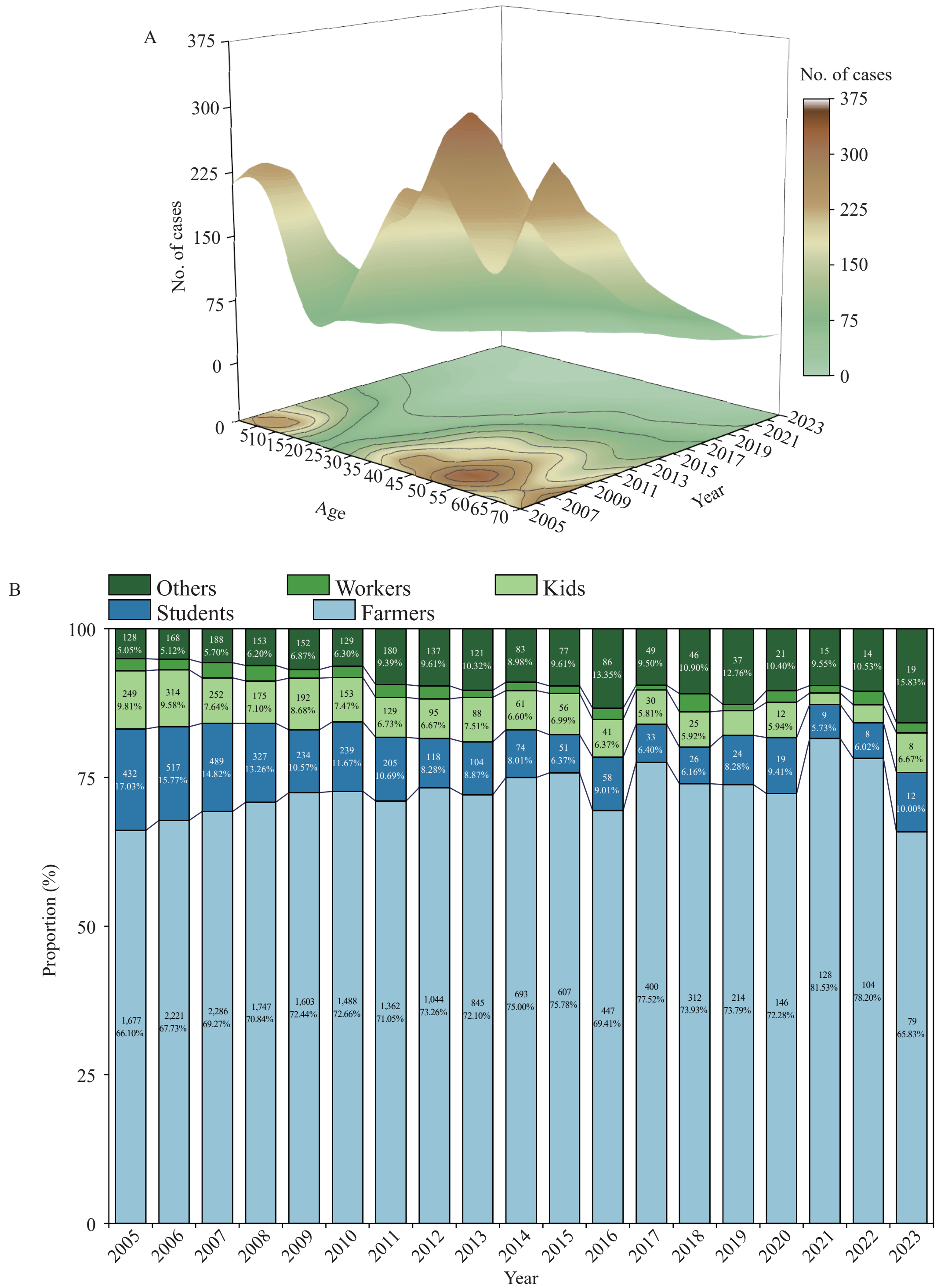
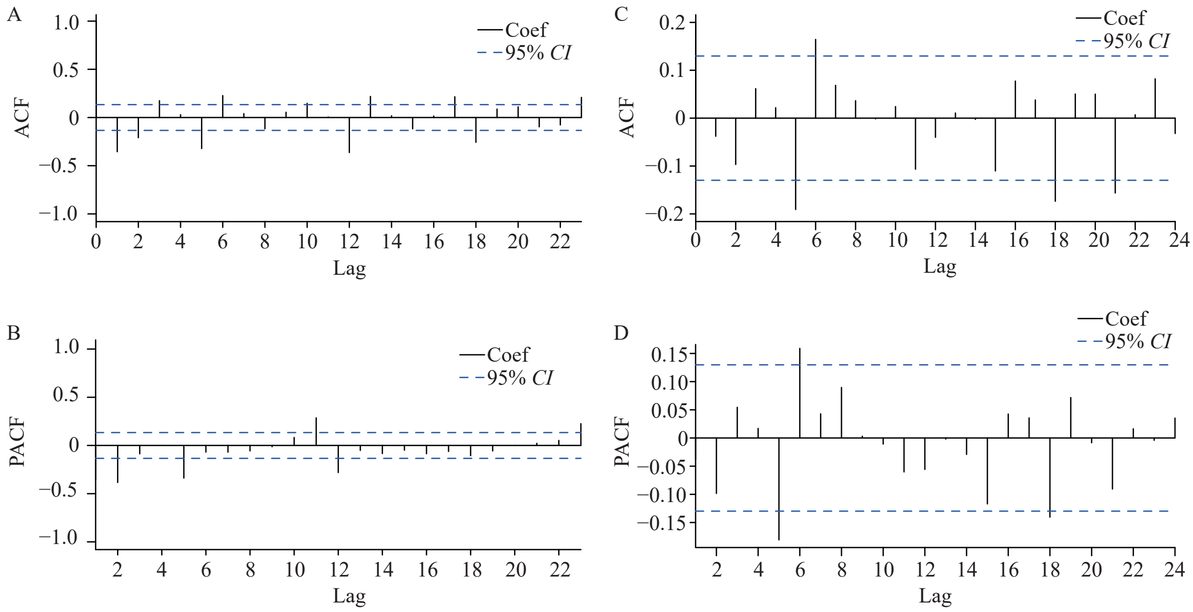
SUPPLEMENTARY MATERIAL



SUPPLEMENTARY FIGURE S1. Monthly distribution of human rabies cases in China from 2005 to 2022.



SUPPLEMENTARY FIGURE S2. Demographic characteristics of human rabies cases in China, 2005–2022. The distribution of human rabies cases by (A) age and (B) occupation.



SUPPLEMENTARY FIGURE S3. Autocorrelation function (ACF) and partial autocorrelation function (PACF) plots of the differencing human rabies cases. (A) ACF plot of the seasonal differential series. (B) PACF plot of the seasonal differential series. (C) ACF plot of residuals after applying the SARIMA $(0,1,2)(2,1,1)_{12}$ model. (D) PACF plot of residuals after applying the SARIMA $(0,1,2)\ (2,1,1)_{12}$ model.

Note: The number of lags is plotted along the *x* axis and the correlation coefficient (−1 to 1) along the *y* axis. Dotted lines indicate 95% *CI*.

Abbreviation: *CI*=confidence interval.

SUPPLEMENTARY TABLE S1. Fitting parameters of eight possible SARIMA models.

Models	AIC	BIC	Log-likelihood	Weighted average
SARIMA $(0,1,2)\ (2,1,1)_{12}$	−7.1	13.12	9.55	−4.36
SARIMA $(0,1,2)\ (0,1,1)_{12}$	−6.08	7.4	7.04	−4.26
SARIMA $(2,1,1)\ (2,1,1)_{12}$	−7.14	16.45	10.6	−3.94
SARIMA $(2,1,1)\ (0,1,1)_{12}$	−5.94	10.91	7.97	−3.66
SARIMA $(1,1,1)\ (0,1,1)_{12}$	−5.16	8.32	6.58	−3.33
SARIMA $(1,1,2)\ (2,1,1)_{12}$	−6.45	17.14	10.23	−3.25
SARIMA $(0,1,1)\ (0,1,1)_{12}$	−4.62	5.49	5.31	−3.25
SARIMA $(1,1,2)\ (0,1,1)_{12}$	−5.33	11.52	7.67	−3.05

Abbreviation: AIC=Akaike Information Criterion; BIC= Bayesian Information Criterion; SARIMA=Seasonal autoregressive integrated moving average.

SUPPLEMENTARY TABLE S2. Parameter estimation and verification of the SARIMA $(0,1,2)\ (2,1,1)_{12}$ model.

Variables	Estimates	Standard Error	t	*P*
MA 2	−0.191	0.071	2.681	0.008
SAR 2	−0.277	0.125	−2.213	0.028
SMAR 1	0.525	0.151	3.474	0.001

Abbreviation: SARIMA=seasonal autoregressive integrated moving average; MA=moving average; SAR=seasonal autoregressive; SMAR=seasonal moving average regressive; *CI*=confidence Interval.

SUPPLEMENTARY TABLE S3. Forecasts and 95% *CI*s of human rabies cases for the next 24 months based on the SARIMA (0,1,2) $(2,1,1)_{12}$ model.

Time	Forecasts	95% *CI*	Time	Forecasts	95% *CI*
24-January	5.134	(3.167, 7.741)	25-January	4.043	(2.216, 7.072)
24-February	7.108	(4.561, 11.819)	25-February	5.598	(2.665, 8.729)
24-March	5.670	(3.444, 9.067)	25-March	4.465	(2.159, 7.205)
24-April	6.766	(4.199, 11.229)	25-April	5.328	(2.664, 9.058)
24-May	6.004	(3.302, 8.964)	25-May	4.728	(1.901, 6.582)
24-June	8.036	(4.614, 12.716)	25-June	6.328	(3.125, 11.018)
24-July	7.825	(4.210, 11.773)	25-July	6.162	(3.272, 11.743)
24-August	9.215	(4.808, 13.645)	25-August	7.257	(3.389, 12.375)
24-September	8.094	(4.443, 12.791)	25-September	6.374	(3.064, 11.385)
24-October	8.639	(4.582, 13.379)	25-October	6.804	(3.303, 12.481)
24-November	6.553	(2.994, 8.864)	25-November	5.160	(2.204, 8.469)
24-December	4.033	(2.219, 6.662)	25-December	3.175	(1.205, 4.709)
Total	83.077	(46.543, 128.650)	Total	65.422	(31.167, 110.826)

Abbreviation: SARIMA=seasonal autoregressive integrated moving average; *CI*=confidence Interval.