# Original Article

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## Abstract

Background Nearly half of global esophageal cancer deaths occur in China, imposing a substantial burden on the public health system and seriously affecting patients' quality of life. Objective This study aimed to analyze the current status and past trends of esophageal cancer mortality from 2010 to 2021 and to predict trends through 2030, in order to provide a reference for optimizing esophageal cancer prevention and control strategies. Methods Esophageal cancer mortality data were collected from the Chinese Cause of Death Surveillance Dataset (2010–2021), and age standardization was performed using data from the Sixth National Population Census. Crude mortality rates and standardized mortality rates were used to describe mortality among Chinese residents by age, sex, urban-rural residence, and region from 2010 to 2021. A Joinpoint regression model was used to analyze trends in the annual percentage change (APC) and average annual percentage change (AAPC) of standardized mortality rates. A GM (1, 1) grey model was established to predict esophageal cancer mortality data from 2022 to 2030. Results From 2010 to 2021, the overall crude mortality rate of esophageal cancer among Chinese residents decreased from 12.05/100,000 in 2010 to 11.70/100,000 in 2021, a decrease of 2.90%; the overall standardized mortality rate decreased from 12.65/100,000 in 2010 to 7.41/100,000 in 2021, a decrease of 41.44%. The crude mortality rate showed marked differences by sex, urban-rural residence, and region, specifically being higher in males than in females, higher in rural areas than in urban areas, and higher in the eastern region than in the central and western regions. Age was an important risk factor for esophageal cancer. From 2010 to 2021, the decreasing trend in the standardized mortality rate of esophageal cancer among females (AAPC=-5.18%, P<0.05) was greater than that among males (AAPC=-3.96%, P<0.05). The standardized mortality rate of esophageal cancer in rural areas showed a downward trend (AAPC=-5.58%, P<0.05), whereas the decreasing trend in urban areas was not significant. The decreasing trend in the standardized mortality rate of esophageal cancer in the central region (AAPC=-6.92%, P<0.05) was greater than that in the eastern region (AAPC=-3.25%, P<0.05), while no significant downward trend was observed in the western region. The GM (1, 1) model predicted that from 2022 to 2030, the crude mortality rate of esophageal cancer in China would decline to 11.70/100,000, and the standardized mortality rate would decline to 6.06/100,000. Conclusion During the study period, the crude mortality status of esophageal cancer in China improved, but the burden remains heavy. Greater attention should be paid to males and elderly residents; early screening, diagnosis, and treatment of esophageal cancer should be strengthened in urban and rural areas as well as in eastern and western regions; and more refined prevention and control measures for esophageal cancer should be implemented by comprehensively considering regional characteristics, population characteristics, and risk factors.

Full Text

## Original Article

# Trend Analysis and Forecasting Study of Changes in Esophageal Cancer Mortality Rates in China from 2010 to 2021

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【Abstract】 **Background** Nearly half of global deaths from esophageal cancer occur in China, imposing a heavy burden on China’ s public health system and seriously affecting patients’ quality of life. **Objective** This study aimed to analyze the current status and historical trends of esophageal cancer mortality from 2010 to 2021 and to forecast trends through 2030, so as to provide evidence for optimizing esophageal cancer prevention and control strategies. **Methods** Data on deaths from esophageal cancer were collected from the *China Cause of Death Surveillance Dataset (2010–2021)*. Age standardization was performed using data from the sixth national population census. Crude mortality and standardized mortality rates were selected to describe mortality among Chinese residents from 2010 to 2021 by age, sex, urban-rural residence, and region. Joinpoint regression models were used to analyze trends in the annual percentage change (APC) and average annual percentage change (AAPC) of standardized mortality rates. A GM (1,1) grey model was established to predict esophageal cancer mortality data from 2022 to 2030. **Results** From 2010 to 2021, the overall crude mortality rate of esophageal cancer among Chinese residents decreased from 12.05/100 000 in 2010 to 11.70/100 000 in 2021, a decline of 2.90%; the overall standardized mortality rate decreased from 12.65/100 000 in 2010 to 7.41/100 000 in 2021, a decline of 41.44%. Crude mortality showed marked differences by sex, urban-rural residence, and region: it was higher in men than in women, higher in rural areas than in urban areas, and higher in eastern China than in central and western China. Age was an important risk factor for esophageal cancer. From 2010 to 2021, the downward trend in the standardized mortality rate of esophageal cancer among women (AAPC=-5.18%, $P$<0.05) was greater than that among men (AAPC=-3.96%, $P$<0.05). The standardized mortality rate of esophageal cancer in rural areas showed a decreasing trend (AAPC=-5.58%, $P$<0.05), whereas the downward trend in urban areas was not significant. The decreasing trend in the standardized mortality rate of esophageal cancer in central China (AAPC=-6.92%, $P$<0.05) was greater than that in eastern China (AAPC=-3.25%, $P$<0.05), while no significant decreasing trend was observed in western China. The GM (1,1) model predicted that from 2022 to 2030, the crude mortality rate of esophageal cancer in China would decrease to 11.70/100 000, and the standardized mortality rate would decrease to 6.06/100 000. **Conclusion** During the study period, the mortality situation for esophageal cancer in China improved, but the burden remained heavy. Greater attention should be paid to men and older residents; early screening and diagnosis/treatment of esophageal cancer should be strengthened in urban and rural areas as well as in eastern and western regions; and more refined esophageal cancer prevention and control efforts should be implemented by comprehensively considering regional characteristics, population characteristics, and risk factors.

【Keywords】Esophageal neoplasms; crude mortality rate; standardized mortality rate; joinpoint regression model; GM (1,1) model

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# Trend Analysis and Forecasting Study of Esophageal Cancer Mortality Rate Change in China from 2010 to 2021

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【Abstract】**Background** China bears a heavy burden of esophageal cancer, accounting for nearly half of global deaths from this disease. This poses a significant threat to public health and severely impairs patients' quality of life. **Objective** This study aimed to assess the current status and historical trends in esophageal cancer mortality from 2010 to 2021, with projections to 2030, to inform the optimization of prevention and control strategies. **Methods** Data on esophageal cancer deaths from the China Cause of Death Surveillance Dataset (2010–2021) were analyzed. Age standardization was performed using data from the sixth population census. Crude and standardized mortality rates were used to describe mortality patterns among Chinese residents, stratified by age, sex, urban–rural residence, and geographic region. Joinpoint regression models were applied to analyze trends in standardized mortality rates, and the annual percentage change (APC) and average annual percentage change

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(AAPC) were calculated. In addition, a GM (1, 1) grey model was constructed to predict deaths from esophageal cancer from 2022 to 2030. **Results** From 2010 to 2021, the crude mortality rate of esophageal cancer in China declined from 12.05/100 000 to 11.70/100 000, representing a decrease of 2.90%. The standardized mortality rate showed a more pronounced decline, falling from 12.65/100 000 to 7.41/100 000, a reduction of 41.44%. Marked disparities were observed, with higher mortality rates among males, rural populations, and residents of the eastern region. Age was an important risk factor. Notably, the decline in the standardized mortality rate was steeper among females ($AAPC$=-5.18%, $P$<0.05) than among males ($AAPC$=-3.96%, $P$<0.05). In rural areas, the decline was significant ($AAPC$=-5.58%, $P$<0.05), whereas the trend in urban areas was less evident. Central China showed a steeper decline ($AAPC$=-6.92%, $P$<0.05) than eastern China ($AAPC$=-3.25%, $P$<0.05), while no significant trend was observed in western China. The GM (1, 1) model predicted that the crude mortality rate of esophageal cancer in China would decrease to 11.70 per 100 000 during 2022-2030, and the standardized mortality rate would drop to 6.06 per 100 000. **Conclusion** Although esophageal cancer mortality in China decreased during the study period, the disease burden remains heavy. Special attention should be paid to males and older adults. Enhanced screening, diagnosis, and treatment are needed in both urban and rural areas, as well as in eastern and western regions. More targeted prevention and control strategies should be developed by taking regional, population, and risk factors into account.

**【Key words】** Esophageal neoplasms; Crude mortality; Standardized mortality; Joinpoint regression model; GM (1, 1) model

Esophageal cancer (EC) is a severe malignant tumor of the digestive tract originating from the esophageal epithelium and has a particularly high incidence in China. It has now become the fourth most fatal cancer in China[1]. Because EC often lacks typical clinical manifestations and signs in the early stage, many patients are already in the middle or late stage at diagnosis, which greatly affects the prognosis of EC and leads to poor overall outcomes. In most countries, the 5-year survival rate after diagnosis of EC is only 10%-30%. Although the survival rate of EC has improved in recent years, it remains generally low[2], and its severe mortality situation has imposed a heavy disease burden on health systems both in China and worldwide. Influenced by multiple factors such as dietary habits, genetics, population size, and population structure[3], EC in China is characterized by particularly high incidence and high mortality. More than half of all EC cases and deaths worldwide occur in China. The Global Burden of Disease Study (GBD) showed that in 2019, more than 250 000 people died from EC in China, accounting for 52.61% of the global total; disability-adjusted life years (DALYs) lost due to EC accounted for approximately 49.37% of the global burden, reaching 5.7599 million person-years, seriously affecting patients' quality of life.

Existing studies have mostly explored the epidemiological characteristics and historical trends in EC incidence and mortality at local regional scales, such as provinces and municipalities[4–5], or have used GBD model-estimated data as the main data source to conduct national-level studies of the EC disease burden[6–7]. Few scholars have used large-scale surveillance data to investigate nationwide changes in EC mortality trends and future projections. In view of the particularly severe mortality situation of EC in China, this study, based on death-cause surveillance data from the national disease surveillance system, analyzed the current epidemiological status and changing trends of EC mortality in China from 2010 to 2021 and predicted the mortality trend of EC from 2022 to 2030, with the aim of providing a reference for increasing clinical experience in EC prevention and treatment in China, formulating more effective EC prevention and control policies, improving patients' quality of life, and reducing the disease burden of EC.

# 1 Data and Methods

## 1.1 Data Sources

Data on the number of EC deaths, crude mortality rates, and population by age, sex, region, and urban/rural residence in China from 2010 to 2021 were obtained from the *China Cause of Death Surveillance Dataset (2010–2021)* published by the Chinese Center for Disease Control and Prevention. The Chinese Center for Disease Control and Prevention Disease Surveillance Points (CDC-DSP) system includes 208 urban sites and 397 rural sites, involving 31 provinces and regions (provincial-level municipalities), and covers approximately one-quarter of the national population. It is the largest cause-of-death surveillance system in China. Through multilevel quality audits, the system collects all death information occurring in each jurisdiction and has formed a stable, well-represented national and provincial cause-of-death surveillance dataset. According to the classification of death data based on the *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision* (ICD-10), the disease code for EC is C15.

## 1.2 Research Methods

### 1.2.1 Data Processing

Because age-specific incidence and mortality rates of EC in China are relatively low before the age of 45, this study selected data for the population aged $ $45 years and divided age groups into 45–54, 55–64, 65–74, 75–84, and $ $85 years.

Crude mortality rates of EC were collected and calculated for populations in different age groups, by sex (male, female), urban/rural residence (urban, rural), and region (eastern, central, western). Because the age-specific population structure data from the Seventh National Population Census have not been released, this study used data from the Sixth National Population Census as the standard population structure to calculate standardized mortality rates for different age groups, sexes, urban/rural residences, and regions. The calculation formula is as follows: $P' = \sum(N_i/N)P_i$ ($P'$ is the standardized mortality rate; $N_i/N$ is the standard age-specific composition ratio, and $P_i$ is the actual age-specific mortality rate).

### 1.2.2 GM (1, 1) Grey Prediction Model

The GM (1, 1) grey prediction model is a time-series forecasting model proposed by Professor Deng Julong in 1987 that is suitable for problems involving small samples and poor information. Its core idea is to perform accumulated generation on the original data to obtain an approximately exponential pattern and then establish a differential equation, thereby fully mining the essence of the system and achieving relatively high prediction accuracy[8]. In this study, the GM (1, 1) model was applied to the 2022–2030 data for different age groups, sexes, urban/rural residences, and regions in China.

Predictions were made for the EC crude mortality rate and standardized mortality rate. The posterior error ratio $C$ and the small-error probability $P$ were used to test the model-fitting accuracy grade; the criteria are shown in Table 1.

**Table 1 Evaluation criteria for the fitting accuracy of the GM (1, 1) model**

| Posterior error ratio $C$ | Small-error probability $P$ | Accuracy grade |
|---|---|---|
| $\leq 0.35$ | $\geq 0.95$ | Grade I (excellent) |
| $> 0.35 \sim 0.50$ | $0.80 \sim< 0.95$ | Grade II (qualified) |
| $> 0.50 \sim 0.65$ | $0.70 \sim< 0.80$ | Grade III (basically qualified) |
| $> 0.65$ | $< 0.70$ | Grade IV (unqualified) |

### 1.3 Statistical analysis

Joinpoint 5.0.1 software was used to perform regression analysis of trends in the standardized EC mortality rate in China from 2010 to 2021. Based on the temporal characteristics of disease, the Joinpoint model identifies inflection points with statistically significant significance, subdivides the study period into multiple independent intervals, and performs trend fitting and optimization, thereby enabling a more detailed assessment of the epidemiological characteristics of disease in different intervals across the overall time span. It is widely used in studies of trends in tumor incidence and mortality. In this study, year was used as the independent variable and standardized mortality rate as the dependent variable to derive a log-linear equation, and the annual percent change (APC), average annual percent change (AAPC), and their 95%$CI$ were calculated. If $AAPC > 0$, the indicator was considered to increase year by year; otherwise, it was considered to decrease year by year. Trend analysis was performed using the $\chi^2$ trend test, with $P < 0.05$ indicating that the trend change was statistically significant.

## 2 Results

### 2.1 Overview of EC mortality among Chinese residents with different characteristics from 2010 to 2021

From 2010 to 2021, there were 319,490 cumulative EC deaths among Chinese residents, including 9,493 deaths in 2010 and 31,339 deaths in 2021. The overall crude mortality rate decreased from 12.05 per 100,000 in 2010 to 11.70 per 100,000 in 2021, a decrease of 2.90%. In terms of sex differences, the mean crude mortality rate among males from 2010 to 2021 was higher than that among females ($Z = -4.158$, $P < 0.05$); in 2021, the crude EC mortality rate among males was 17.28 per 100,000, an increase of 0.17% compared with 2010 (17.25 per 100,000). By contrast, the crude EC mortality rate among females showed a downward trend over time, with a decrease of 10.54%. In terms of urban-rural differences, the mean crude mortality rate in rural areas from 2010 to 2021 was higher than that in urban areas ($Z = -4.157$, $P < 0.05$). During the study period, the crude EC mortality rate in urban areas showed a fluctuating upward trend, increasing by 14.04%, whereas the crude EC mortality rate in rural areas showed a downward trend, decreasing by 10.40%. In terms of regional differences, the mean crude mortality rate in eastern China from 2010 to 2021 was higher than those in central and western China ($Z = -3.754$, $P < 0.05$; $Z = -3.984$, $P < 0.05$), while the difference in the mean crude mortality rate between central and western China was not statistically significant ($Z = -1.675$, $P = 0.094$). During this period, crude EC mortality rates in eastern and western China both increased, by 5.23% and 7.71%, respectively; in central China, the rate decreased from 12.85 per 100,000 in 2010 to 10.35 per 100,000 in 2021, a decrease of 19.46%.

In terms of age differences, the crude EC mortality rate among Chinese residents from 2010 to 2021 showed an increasing trend with age ($\chi^2_{\text{trend}} = 83.519$, $P < 0.05$) and reached a peak in the age group $\geq$ 85 years. See Figure 1 and Table 2. After eliminating the influence of age structure and comparing standardized mortality rates, the overall standardized EC mortality rate decreased from 12.65 per 100,000 in 2010 to 7.41 per 100,000 in 2021, a decrease of 41.44%. Compared with 2010, in 2021 the EC standardized prevalence rates among Chinese populations of different sex, residence, and regional groups all decreased; among them, central China decreased from 13.86 per 100,000 in 2010 to 6.77 per 100,000 in 2021, the largest decrease, at 51.17%. The decreases in

EC standardized mortality rates among males, females, rural residents, eastern residents, and western residents were 36.03%, 45.94%, 20.31%, 47.51%, 31.79%, and 31.88%, respectively. See Table 2.

### 2.2 Joinpoint regression analysis of EC mortality in China from 2010 to 2021

The Joinpoint regression analysis showed that the overall standardized EC mortality rate in China showed a downward trend from 2010 to 2021, with an $AAPC$ of $-4.62\%$ ($95\%CI = -5.89\% \sim -3.34\%$). Period-specific analysis showed that the downward trend was most pronounced from 2017 to 2021, with an $APC$ of $-7.71\%$ ($95\%CI = -9.95\% \sim -5.41\%$). In terms of sex differences, EC standardized mortality rates among populations of different sex all showed downward trends during the study period; the decrease among females ($AAPC = -5.18\%$, $95\%CI = -7.53\% \sim -2.77\%$) was greater than that among males ($AAPC = -3.96\%$, $95\%CI = -5.24\% \sim -2.66\%$). In terms of place of residence, the standardized EC mortality rate in rural areas showed a downward trend over time, with an $AAPC$ of $-5.58\%$ ($95\%CI = -6.97\% \sim -4.17\%$); the standardized EC mortality rate in urban areas showed no significant trend over time ($P > 0.05$). In terms of regional differences, EC standardized mortality rates in eastern and central China both showed downward trends during the study period; the decrease in central China ($AAPC = -6.92\%$, $95\%CI = -10.99\% \sim -2.66\%$) was greater than that in eastern China ($AAPC = -3.25\%$, $95\%CI = -4.29\% \sim -2.19\%$). The EC standardized mortality rate in western China showed no obvious trend over time ($P > 0.05$); see Table 3.

### 2.3 EC among Chinese residents in China from 2022 to 2030 based on GM (1, 1)

**Figure 1 Crude mortality rate of EC in different age groups aged 45 years and above in China from 2010 to 2021**

**Table 2 Crude mortality rate and standardized mortality rate of esophageal cancer in China from 2010 to 2021 (1/100,000)**

| Indicator | Year (year) | Overall | Sex—Male | Sex—Female | Place of residence—Urban | Place of residence—Rural | Region—Eastern | Region—Central | Region—Western |
|---|---|---|---|---|---|---|---|---|---|
| Crude mortality rate (1/100,000) | 2010 | 12.05 | 17.25 | 6.64 | 8.62 | 14.14 | 12.61 | 12.85 | 10.24 |
| Crude mortality rate (1/100,000) | 2011 | 12.03 | 17.28 | 6.59 | 8.20 | 14.57 | 12.35 | 12.78 | 10.54 |
| Crude mortality rate (1/100,000) | 2012 | 11.84 | 17.19 | 6.29 | 8.35 | 14.16 | 11.79 | 12.20 | 11.44 |
| Crude mortality rate (1/100,000) | 2013 | 12.54 | 18.14 | 6.72 | 10.36 | 13.52 | 15.05 | 10.17 | 12.10 |
| Crude mortality rate (1/100,000) | 2014 | 12.84 | 18.66 | 6.78 | 11.12 | 13.64 | 15.22 | 10.53 | 12.37 |
| Crude mortality rate (1/100,000) | 2015 | 12.57 | 18.23 | 6.74 | 10.88 | 13.38 | 15.31 | 10.28 | 11.63 |

| Indicator | Year (year) | Overall | Sex—Male | Sex—Female | Place of residence—Urban | Place of residence—Rural | Region—Eastern | Region—Central | Region—Western |
|---|---|---|---|---|---|---|---|---|---|
| Crude mortality rate (1/100,000) | 2016 | 12.51 | 18.22 | 6.60 | 10.87 | 13.34 | 15.29 | 10.20 | 11.53 |
| Crude mortality rate (1/100,000) | 2017 | 12.49 | 18.24 | 6.55 | 11.03 | 13.24 | 14.60 | 10.71 | 11.69 |
| Crude mortality rate (1/100,000) | 2018 | 12.36 | 18.09 | 6.43 | 11.01 | 13.06 | 14.46 | 10.45 | 11.73 |
| Crude mortality rate (1/100,000) | 2019 | 12.01 | 17.75 | 6.09 | 10.03 | 13.04 | 13.83 | 10.53 | 11.22 |
| Crude mortality rate (1/100,000) | 2020 | 11.79 | 17.47 | 5.93 | 10.08 | 12.71 | 13.62 | 10.37 | 10.92 |
| Crude mortality rate (1/100,000) | 2021 | 11.70 | 17.28 | 5.94 | 9.83 | 12.67 | 13.27 | 10.35 | 11.03 |

| Indicator | Year (year) | Overall | Sex—Male | Sex—Female | Place of residence—Urban | Place of residence—Rural | Region—Eastern | Region—Central | Region—Western |
|---|---|---|---|---|---|---|---|---|---|
| Crude mortality rate (1/100,000) | Mean | 12.23 | 17.82 | 6.44 | 10.03 | 13.46 | 13.95 | 10.95 | 11.37 |
| Standardized mortality rate (1/100,000) | 2010 | 12.65 | 18.00 | 6.98 | 7.13 | 17.67 | 12.25 | 13.86 | 11.34 |
| Standardized mortality rate (1/100,000) | 2011 | 11.70 | 17.17 | 6.32 | 7.02 | 15.95 | 11.16 | 13.15 | 10.95 |
| Standardized mortality rate (1/100,000) | 2012 | 11.07 | 16.23 | 5.81 | 6.89 | 14.74 | 10.32 | 11.80 | 11.59 |
| Standardized mortality rate (1/100,000) | 2013 | 9.50 | 15.79 | 5.86 | 7.65 | 14.27 | 12.58 | 9.79 | 10.88 |
| Standardized mortality rate (1/100,000) | 2014 | 11.01 | 15.34 | 5.80 | 8.43 | 13.03 | 12.56 | 8.43 | 9.57 |

| Indicator | Year (year) | Overall | Sex—Male | Sex—Female | Place of residence—Urban | Place of residence—Rural | Region—Eastern | Region—Central | Region—Western |
|---|---|---|---|---|---|---|---|---|---|
| Standardized mortality rate (1/100,000) | 2015 | 10.80 | 15.57 | 5.82 | 8.27 | 12.84 | 12.36 | 9.24 | 10.37 |
| Standardized mortality rate (1/100,000) | 2016 | 10.03 | 14.70 | 5.18 | 8.84 | 12.38 | 11.63 | 11.63 | 11.63 |
| Standardized mortality rate (1/100,000) | 2017 | 10.14 | 14.27 | 5.12 | 7.93 | 11.63 | 10.85 | 10.85 | 10.85 |
| Standardized mortality rate (1/100,000) | 2018 | 9.41 | 13.90 | 4.74 | 7.50 | 11.01 | 10.31 | 10.31 | 10.31 |
| Standardized mortality rate (1/100,000) | 2019 | 9.00 | 13.37 | 4.57 | 6.55 | 11.02 | 9.77 | 8.11 | 7.93 |
| Standardized mortality rate (1/100,000) | 2020 | 8.24 | 12.57 | 4.18 | 6.21 | 10.23 | 9.14 | 7.56 | 8.40 |

| Indicator | Year (year) | Overall | Sex—Male | Sex—Female | Place of residence—Urban | Place of residence—Rural | Region—Eastern | Region—Central | Region—Western |
|---|---|---|---|---|---|---|---|---|---|
| Standardized mortality rate (1/100,000) | 2021 | 7.41 | 11.51 | 3.78 | 5.68 | 9.28 | 8.36 | 6.77 | 7.72 |
| Standardized mortality rate (1/100,000) | Mean | 10.08 | 14.87 | 5.35 | 7.34 | 12.84 | 10.94 | 10.12 | 10.13 |

Note: EC = esophageal cancer.

## Mortality-rate prediction

### 2.3.1 Establishment and testing of the GM(1,1) model

Using the crude mortality rate and standardized mortality rate of EC among Chinese residents from 2010 to 2021 as the baseline, GM(1,1) grey prediction models were established separately for EC mortality among Chinese residents from 2022 to 2030. System modeling was performed for the crude mortality rate, yielding a development coefficient $a = 0.003$ and a grey action quantity $b = 12.503$. The time-response equation of the prediction model was $\hat{X} = -3827.616e^{-0.003k}+3839.666$. Testing of the model's prediction accuracy yielded a posterior error ratio $C = 0.131$, a small-error probability $P = 0.833$, and a mean relative deviation $MRD = 2.539\%$; the model-fitting grade was Grade II (qualified).

System modeling was performed for the standardized mortality rate, yielding a development coefficient $a = 0.034$ and a grey action quantity $b = 12.255$. The time-response equation was $\hat{X} = -345.195e^{-0.034k} + 357.849$. Testing of the model' s prediction accuracy yielded a posterior error ratio $C = 0.079$, a small-error probability $P = 1$, and a mean relative deviation $MRD = 4.475\%$; the model-fitting grade was Grade I (excellent). Both models had good prediction accuracy, and $-a \leq 0.3$ in both cases, suggesting that medium- and long-term prediction could be performed.

### 2.3.2 Prediction of crude mortality rate and standardized mortality rate of EC among Chinese residents from 2022 to 2030

The prediction results showed that the crude mortality rates of EC among Chinese residents from 2022 to 2030 were 12.01, 11.97, 11.93, 11.89, 11.85, 11.77, 11.74, and 11.70, respectively, indicating a continuous downward trend, with an average annual decrease of 0.33%. The standardized mortality rates of EC among Chinese residents from 2022 to 2030 were 7.97, 7.71, 7.45, 7.20, 6.95, 6.72, 6.49, 6.27, and 6.06, respectively, likewise showing a year-by-year downward trend, with an average annual decrease of 3.37%.

## 3 Discussion

This study collected data on EC deaths from the *Chinese Cause-of-Death Surveillance Dataset* for 2010–2021, explored the current status and historical trends of EC mortality in China, and constructed a GM(1,1) model to predict future development trends in EC.

The study results showed that, from 2010 to 2021, the overall crude mortality rate of EC in China

**Table 3** Joinpoint-analysis of the trend of standardized mortality of esophageal cancer in China from 2010 to 2021

| Group | Indicator | Trend period (years) | Change value (%) | 95% CI (%) | $t$ value | $P$ value |
|---|---|---|---|---|---|---|
| Overall | APC | 2010–2013 | −6.93 | −10.26~−3.48 | −5.477 | 0.005 |
| Overall | APC | 2013–2017 | 0.39 | −3.27~4.19 | 0.291 | 0.786 |
| Overall | APC | 2017–2021 | −7.71 | −9.95~−5.41 | −9.067 | 0.001 |
| Overall | AAPC | 2010–2021 | −4.62 | −5.89~−3.34 | −6.921 | <0.001 |
| Sex | | | | | | |
| Male | APC | 2010–2012 | −4.77 | −10.84~1.71 | −2.060 | 0.108 |
| Male | APC | 2012–2019 | −2.63 | −3.71~−1.55 | −6.678 | 0.003 |
| Male | APC | 2019–2021 | −7.68 | −14.05~−0.84 | −3.104 | 0.036 |
| Male | AAPC | 2010–2021 | −3.96 | −5.24~−2.66 | −5.894 | <0.001 |
| Female | APC | 2010–2012 | −8.48 | −17.26~1.23 | −2.440 | 0.071 |

| Group | Indicator | Trend period (years) | Change value (%) | 95% CI (%) | $t$ value | $P$ value |
|---|---|---|---|---|---|---|
| Female | APC | 2012–2015 | −0.36 | −10.28~10.66 | −0.095 | 0.929 |
| Female | APC | 2015–2021 | −6.40 | −8.21~−4.56 | −9.423 | 0.001 |
| Female | AAPC | 2010–2021 | −5.18 | −7.53~−2.77 | −4.147 | 0.000 |
| Place of residence | | | | | | |
| Urban | APC | 2010–2012 | 0.25 | −10.96~12.86 | 0.058 | 0.957 |
| Urban | APC | 2012–2016 | 5.66 | −0.23~11.91 | 2.662 | 0.056 |
| Urban | APC | 2016–2021 | −8.73 | −11.23~−6.17 | −9.158 | 0.001 |
| Urban | AAPC | 2010–2021 | −2.08 | −4.31~0.19 | −1.797 | 0.072 |
| Rural | APC | 2010–2012 | −8.85 | −15.11~−2.13 | −3.616 | 0.022 |
| Rural | APC | 2012–2019 | −4.29 | −5.43~−3.13 | −10.129 | 0.001 |
| Rural | APC | 2019–2021 | −6.74 | −13.97~1.09 | −2.402 | 0.074 |
| Rural | AAPC | 2010–2021 | −5.58 | −6.97~−4.17 | −7.593 | <0.001 |
| Region | | | | | | |
| Eastern | APC | 2010–2012 | −5.02 | −9.15~−0.70 | −3.212 | 0.033 |
| Eastern | APC | 2012–2015 | 5.34 | 0.68~10.21 | 3.190 | 0.033 |
| Eastern | APC | 2015–2021 | −6.70 | −7.45~−5.94 | −23.767 | 0.000 |
| Eastern | AAPC | 2010–2021 | −3.25 | −4.29~−2.19 | −5.950 | <0.001 |
| Central | APC | 2010–2014 | −11.89 | −17.26~−6.18 | −5.593 | 0.005 |
| Central | APC | 2014–2017 | 9.49 | −10.20~33.51 | 1.270 | 0.273 |
| Central | APC | 2017–2021 | −12.94 | −18.45~−7.05 | −5.880 | 0.004 |
| Central | AAPC | 2010–2021 | −6.92 | −10.99~−2.66 | −3.141 | 0.002 |

| Group | Indicator | Trend period (years) | Change value (%) | 95% CI (%) | $t$ value | $P$ value |
|---|---|---|---|---|---|---|
| Western | APC | 2010–2014 | −3.09 | −11.19~5.76 | −0.996 | 0.376 |
| Western | APC | 2014–2017 | 2.44 | −23.44~37.07 | 0.230 | 0.829 |
| Western | APC | 2017–2021 | −9.54 | −17.93~−0.28 | −2.855 | 0.046 |
| Western | AAPC | 2010–2021 | −4.04 | −10.11~2.44 | −1.237 | 0.216 |

Note: APC = annual percentage change; AAPC = average annual percentage change.

**Table 3** GM(1,1) model test results of crude and standardized esophageal cancer mortality among Chinese residents from 2022 to 2030

| Model | a | b | C | P | MRD (%) | Model fitting grade |
|---|---|---|---|---|---|---|
| Crude mortality | 0.003 | 12.503 | 0.131 | 0.833 | 2.539 | Grade II (acceptable) |
| Standardized mortality | 0.034 | 12.255 | 0.079 | 1.000 | 4.475 | Grade I (excellent) |

Note: a is the development coefficient; b is the gray action quantity; c is the posterior error ratio; P is the small-error probability; MRD is the mean relative error.

The rates showed a downward trend, and the mortality level differed by sex, place of residence, region, and age. In terms of age differences, the main manifestation was that the mean crude mortality of EC among males was higher than that among females, consistent with previous studies

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. This may be related to differences between sexes in the types and opportunities of occupational exposure; the ability of estrogen receptors in females to inhibit the growth and malignant progression of EC cells

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; men' s relatively lower awareness of self-health management than women' s; and the higher prevalence among men of unhealthy lifestyle habits, especially smoking and alcohol consumption. According to GBD estimates, in 2019 the proportion of deaths among Chinese males attributable to smoking was 16.11%, and the proportion attributable to alcohol consumption was 8.14%, respectively being

**Table 4** GM (1, 1) prediction results for the crude mortality rate and standardized mortality rate of esophageal cancer among Chinese residents from 2022 to 2030

| Year | Crude mortality rate (per 100,000) | Standardized mortality rate (per 100,000) |
|---|---|---|
| 2022 | 12.01 | 7.97 |
| 2023 | 11.97 | 7.71 |
| 2024 | 11.93 | 7.45 |
| 2025 | 11.89 | 7.20 |
| 2026 | 11.85 | 6.95 |
| 2027 | 11.81 | 6.72 |
| 2028 | 11.77 | 6.49 |
| 2029 | 11.74 | 6.27 |
| 2030 | 11.70 | 6.06 |
| Average annual growth rate | −0.33% | −3.37% |

18.55 times and 18.43 times those of women, respectively. In terms of differences by place of residence, during the study period the mean crude mortality rate of EC in rural areas was higher than that in urban areas, which is consistent with the study by Song Ling et al. [11]. On the one hand, rural areas often have particular dietary habits, with a preference for pickled foods, salted vegetables, and similar foods, increasing the risk of EC; on the other hand, medical and health resources in rural areas are relatively scarce, and residents' awareness of cancer prevention is weaker, making them more likely to miss early screening and diagnosis of EC as well as the optimal treatment window. In addition, rural residents are more likely to have long-term exposure to pesticides or other chemical substances, and environmental and occupational exposures related to EC are, to a certain extent, higher than in urban areas, resulting in the persistently higher EC mortality rate in rural areas. It is worth noting that, because urban–rural differences in EC risk factors such as smoking, alcohol consumption, dietary habits, and dietary structure are gradually narrowing [12], the EC mortality rate in urban areas showed a fluctuating upward trend during the study period and gradually approached the EC mortality level in rural areas. Regarding regional differences, during the study period the crude EC mortality rate in the eastern region increased somewhat, and its mean value was higher than those in the central and western regions. Compared with the central and western regions, the eastern region has a larger population base, more complete public health services, and a longer average life expectancy; this feature is consistent with the increase in EC mortality with age. Further analysis found that, after adjustment for age structure, the gap in EC mortality between the eastern region and the central and western regions narrowed, indicating to some extent that population aging is a notable factor leading to the higher EC mortality rate in the eastern region. In terms of age differences, from 2020 to 2021, the risk of EC death increased with age and peaked in the age group of 85 years and above, consistent with previous research findings [13].

The results of Joinpoint regression analysis showed that, from 2010 to 2021, the AAPC values of standardized EC mortality rates overall and among men, women, rural residents, and residents of the eastern and central regions in China all showed downward trends, indicating that in recent years China has achieved notable results through prevention and control measures targeting EC risk factors such as smoking, alcohol consumption, and unhealthy dietary habits, as well as through EC screening, diagnosis, and treatment programs successively carried out in urban and rural areas. Further study found that, in terms of sex differences, the standardized EC mortality rate among women showed a more pronounced downward trend than that among men; in terms of urban–rural differences, the standardized EC mortality rate in rural areas likewise showed a downward trend, whereas this trend was not significant in urban areas. Regional comparisons showed that the decline in the standardized EC mortality rate was more pronounced in the central region, exceeding that in the eastern region, while the western region did not show an obvious downward trend. This heterogeneity in changes in standardized mortality rates is not only related to differences in genetic factors, dietary and lifestyle habits, environmental factors, and other factors among populations of different sex, urban–rural status, and region [14], but may also be influenced by multiple complex factors such as the distribution of medical resources, the level of socioeconomic development, and the implementation priorities of national health policies. In 2005, China first launched EC screening and early diagnosis and treatment programs in eight high-incidence rural areas; subsequently, in 2012, it launched urban EC screening and early diagnosis and treatment programs, with coverage expanding to 29 provinces, municipalities directly under the central government, and autonomous regions nationwide. The preferential implementation of EC prevention and control measures may be an important reason for the marked downward trend in rural EC mortality. At the same time, however, differences in changes in standardized EC mortality rates among populations of different sex and region also indicate that, when the same screening and treatment strategies are applied to populations with different characteristics, changes in mortality show significant heterogeneity. This suggests that regional characteristics, population features, and possible risk factors should be comprehensively considered, and more refined and targeted preventive measures should be formulated and implemented to achieve effective control of EC mortality.

According to predictions from the GM (1, 1) model, the disease burden of EC mortality in China will improve from 2022 to 2030: the crude mortality rate will decline from 12.01 per 100,000 to 11.70 per 100,000, and the standardized mortality rate will decline from 7.97 per 100,000 to 6.06 per 100,000; the model showed good prediction accuracy. Nevertheless, for a long period in the future, EC will remain a major cause of cancer-related death in China and worldwide. At the same time, because of the intensification of population aging and changes in population structure in China, the numbers of EC incident cases and deaths will continue to increase, and China' s EC burden will remain relatively heavy. Maintaining healthy lifestyle habits has a significant effect on reducing the risk of EC death, including limiting tobacco and alcohol intake, reducing consumption of pickled foods, avoiding moldy foods, and increasing intake of fresh fruits and vegetables. In the future, China should continue to strengthen policies related to controlling EC risk factors and make reducing EC mortality a long-term work priority.

## 4 Summary

From 2010 to 2021, the overall crude mortality rate and age-standardized mortality rate of EC in China decreased. It is predicted that from 2022 to 2030, both the crude mortality rate and the standardized mortality rate of EC in China will show year-by-year downward trends. Although China has achieved remarkable progress in EC prevention and treatment in recent years, EC remains an important source of cancer deaths and burden in China and worldwide. In 2021, the crude mortality rates among men, urban residents, and residents of the eastern and western regions increased compared with 2010. Mortality levels were characterized by being higher in men than in women, higher in rural areas than in urban areas, and higher in the eastern region than in the central and western regions; age is an important EC risk factor. The downward trend in standardized EC mortality among women was greater than that among men; standardized EC mortality in rural areas showed a downward trend, whereas the downward trend in urban areas was not obvious; the decline in standardized EC mortality in the central region was greater than that in the eastern region, and the western region showed no obvious downward trend. Men and older adults should be regarded as key populations for EC prevention and control, and the intensity and coverage of early EC screening, diagnosis, and treatment should be increased among urban residents and residents of the eastern and western regions. Education on cancer prevention and anticancer knowledge should be further strengthened, active and healthy dietary and lifestyle habits should be advocated, and smoking cessation and alcohol restriction should be promoted [15]; moreover, refined EC prevention and control policies for high-risk populations and regions should be continuously strengthened, so as to reduce the domestic EC disease burden and improve patient survival and

quality of life, thereby providing clinical experience and important reference for the global prevention and control of EC.

**Research limitations:** Because information from the data sources was limited, this study did not comprehensively cover multiple risk factors related to EC, such as lifestyle and behavioral patterns, genetic characteristics, and the environment. The analytical inferences of the results were mainly based on mortality values and findings from other studies. In addition, this study only explored the current status and trends of EC mortality, and lacked an analysis of trends in the incidence of EC in China. In the future, the scope of data collection will be further expanded to include information on EC incidence and more related risk factors.

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