Heliyon 10 (2024) e34114

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Global burden of bladder cancer attributable to smoking in 204 countries and territories, 1990–2019

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ARTICLE INFO

Keywords:
Burden of disease
GBD study
Bladder cancer
Smoking
Mortality
Disability-adjusted life-years

ABSTRACT

Bladder cancer (BCa) poses a significant medical burden worldwide. However, the epidemiological pattern of the global smoking-induced BCa burden is unclear. Our analysis of the 2019 Global Burden of Disease (GBD) database showed a significant increase in the number of BCa cases worldwide from 1990 to 2019, with a clear upward trend in both age-standardized prevalence and incidence. In contrast, age-standardized rates of mortality (ASMR) and disability-adjusted life-years (ASDR) showed a downward trend, despite an increase in the absolute number of death and disability-adjusted life years. The burden of BCa caused by smoking is greater in males, middle-aged and older adults, and people in countries with high-middle socio-demographic indices (SDI). The study highlights the continuing global health challenge posed by smoking-related BCa. Targeted health policies and interventions are critical, especially in areas with high smoking rates and low socioeconomic status.

1. Introduction

Globally, bladder cancer (BCa) constitutes a significant health concern and is among the most common malignancies of the urinary system [1]. In 2020, there were approximately 573,000 new cases diagnosed worldwide, and BCa was responsible for about 213,000 deaths, significantly impacting human health [1]. Over the years, there has been a notable increase in the incidence of BCa. According to the American Cancer Society, in 2022, BCa ranked as the fourth most common cancer and the eighth leading cause of cancer-related death among males in the United States [2]. In China, BCa incidence tops the list of urogenital system tumors and has shown an upward trend annually [3]. Notably, this malignancy presents unique challenges due to its high recurrence rate and the need for lifelong surveillance, contributing to its distinction as one of the most expensive cancers to manage on a per-patient basis. The burden of BCa is particularly pronounced in males, who exhibit a higher incidence rate than females. This gender disparity underscores the need for

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https://doi.org/10.1016/j.heliyon.2024.e34114
Received 17 March 2024; Received in revised form 17 April 2024; Accepted 3 July 2024
Available online 6 July 2024

targeted research and policy interventions.

BCa is a multifactorial disease, with various genetic and environmental factors contributing to its development [4]. Smoking has been firmly established as the primary risk factor for BCa, a fact supported by numerous studies [4,5]. Tobacco contains many known carcinogens, including aromatic amines and *N*-nitroso compounds, which are excreted in urine and come into close contact with the bladder mucosa [6]. Compared to non-smokers, smokers have a 2–5 times higher risk of developing BCa [1]. Despite a general decline in smoking rates from 1990 to 2019, the absolute number of smokers has increased globally due to population growth [7]. The tobacco epidemic continues to be one of the most significant public health threats the world has ever faced.

However, the epidemiological pattern of BCa burden attributable to smoking at the global level remains unclear. This study leverages data from the 2019 Global Burden of Disease (GBD) study, which provides systematic and updated data on a wide array of diseases and risk factors across more than 204 countries and territories [8,9]. It aims to elucidate the spatio-temporal trends of BCa burden due to smoking. This research represents a pioneering effort to quantitatively assess the global impact of smoking on BCa, offering crucial insights for policymakers and healthcare stakeholders to formulate effective strategies and interventions for better strategic planning and policy implementation.

2. Materials and methods

2.1. Data sources

The annual number of BCa-related deaths, disability-adjusted life-years (DALYs), age-standardized mortality rate (ASMR) and age-standardized DALY rate (ASDR) attributable to smoking were extracted by year, age, region and country from 1990 to 2019 from the Global Health Data Exchange (GHDx) query tool [8]. The GBD is a publicly accessible database containing de-identified data for all participants. The data were accessible for a total of 204 countries and territories. The socio-demographic index (SDI), a comprehensive indicator of development that is closely related to health outcomes, was developed by GBD researchers to classify countries and regions into 5 quintiles (low, low-middle, middle, high-middle, and high) [8]. The world is further categorized into 21 regions based on epidemiological similarity and geographic proximity, in addition to that. We extracted 12 age categories, consisting of 5-year age groups ranging from 30 to 94 years, as well as a category for individuals aged $\geq$95 years, in order to investigate mortality and DALY patterns across different age groups. We also analyzed the burden of BCa attributable to smoking according to age subgroups of 30–49 years, 50–74 years, and 75 years or older. The GHDx query tool was utilized to extract the number of bladder cancer deaths, DALYs, ASMR, and ASDR attributable to smoking from 1990 to 2019. These data were categorized by year, age group, region, and country. The general methodology of the GBD Study 2019 and the methodology for estimating disease burden have been detailed in previous studies [9,10]. In brief, the GBD estimates incidence, prevalence, mortality and DALY due to 369 diseases and injuries in 204 countries and territories. Cause-specific mortality and cause scores were calculated using pooled models of causes of death and spatio-temporal Gaussian process regression. Cause-specific deaths were adjusted to match the total number of all-cause deaths calculated as part of the GBD population, fertility, and mortality estimates. The Bayesian meta-regression modeling tool DisMod-MR 2.1 was used to ensure agreement between incidence, prevalence, remission rate, excess mortality, and cause-specific mortality for most causes. GBD uses a stratified list of risk factors in order to assess specific risk factors and associated summaries. Exposure levels for dichotomous, multifactorial, and continuous risk factors were summarized using pooled exposure values to facilitate comparisons across times, locations, and risks.

2.2. Definitions

In GBD 2019, The incidence and mortality of BCa corresponding to the International Classification of Diseases 10 (ICD-10) codes are C67–C67.9, Z12.6-Z12.79, Z80.52, Z85.51 and C67–C67.9, D09.0, D30.3, D41.4-D41.8, D49.4, respectively [11]. Smoking was defined as the prevalence of current use of any smoking tobacco product and the prevalence of previous use of any smoking tobacco product. In current smokers, it indicates cigarette equivalents smoked per day and cumulative years of exposure per smoker, while in former smokers, the distribution of years since quitting is estimated [12].

The SDI estimated by GBD researchers is expressed on a scale of 0–1 and is estimated based on lagged distribution income (LDI) per capita, average education level of those aged 15 years and older (EDU15+), and total fertility rate under age 25 (TFU25) [8–10]. DALY is a summary measure to quantify the overall burden of disease. It represents the sum of years of life lost and years lived with disability due to premature death [10,12,13]. One DALY can be considered as a loss of 1 year of full health [14]. GBD 2019's modeling strategy for estimating DALY has been described in detail elsewhere [10,13].

2.3. Statistical analyses

First, we analyzed global age-standardized rate (ASR) changes in BCa incidence, prevalence, mortality, and DALY from 1990 to 2019 to shed light on trends in disease burden over this period. Subsequently, the global BCa burden due to smoking from 1990 to 2019 was clarified. Attributable burden analysis was then performed by year, age, sex, region, and SDI to clarify the effect of smoking on BCa. ASR is a classical epidemiological method that minimizes confounding effects due to differences in the age structure of the population [15]. The formula is as follows: $ASR = \frac{\sum_{i=1}^{A} a_i w_i}{\sum_{i=1}^{A} w_i} \times 100000$. The ASR (per 100,000 population) is equivalent to the sum of the

product of the age-specific rate (a_i, where i denotes the ith age class) and the number of persons (or weight) (w_i) in the same age subgroup i of the selected reference standard population, then divided by the sum of standard population weights. All cases and their corresponding ASRs (per 100,000 population) were recorded with 95 % uncertainty intervals (UIs) [16]. DALYs were the sum of years lived with disability (YLDs) and years of life lost (YLL). One DALY represents a loss of the equivalent to one year of full health [10]. In addition, the Annual Percentage Change (APC) was employed to estimate the rate of change over a given time period [17]. In the evaluation of time trends of ASMRs and ASDRs, a joined point regression model was utilized. The "joined points" connected several line segments on a logarithmic scale, which illustrated changes in trends and determined points where the slope of the trend line significantly altered over time. The APC is calculated using the following formula: $APC = \left[\frac{y_{x_1} - y_x}{y_x}\right] \times 100 = \left(e^{\beta_1} - 1\right) \times 100$. In the formula mentioned above, where "y" represents the rate, "x" represents the year, and β_1 is the regression coefficient, the 95 % confidence intervals (CIs) were obtained through a linear regression model.

All the aforementioned analyses were conducted using R software (R Core Team, version 3.5.2, Vienna, Austria). The data were presented as numerical values, along with their 95 % CIs or 95 % UIs. Pearson correlation test, Gaussian process regression model combined with the Loess smoother and Spearman rank order correlation test were employed to evaluate the relationship between smoking-induced BCa burden and SDI, aiming to determine the impact of sociodemographic variables on this burden.

3. Results

3.1. Trends in global disease burden of BCa from 1990 to 2019

Over the three-decade period from 1990 to 2019, there was a considerable increase in the global disease burden of BCa, as evidenced by the data presented in Fig. 1 and Supplementary Table S1. This period saw a significant rise in the age-standardized prevalence rate of BCa, escalating from 28.11 per 100,000 people (95 % UI: 27.13–29.03) in 1990 to 34.92 per 100,000 people (95 % UI: 31.87–37.9) in 2019. Correspondingly, the absolute prevalence numbers also surged, growing from 1.119 million cases (95 % UI: 1.083–1.154) in 1990 to 2.869 million cases (95 % UI: 2.614–3.114) in 2019. A parallel upward trajectory was observed in the incidence of BCa. The total number of new cases annually increased dramatically from 0.235 million (95 % UI: 0.235–0.243) in 1990 to 0.524 million (95 % UI: 0.476–0.569) in 2019. Similarly, the age-standardized incidence rate experienced a modest rise, moving from 6.27 per 100,000 people (95 % UI: 5.98–6.5) in 1990 to 6.52 per 100,000 people (95 % UI: 5.93–7.09) in 2019. In contrast to the increasing trends in prevalence and incidence, ASMR for BCa exhibited a decrease, dropping from 3.49 per 100,000 people (95 % UI: 3.27–3.66) in 1990 to 2.94 per 100,000 people (95 % UI: 2.7–3.13) in 2019. However, it is crucial to note that the absolute number of global BCa deaths showed an 89.3 % increase, rising from 0.121 million (95 % UI: 0.115–0.127) in 1990 to 0.229 million (95 % UI: 0.211–0.243) in 2019.

Furthermore, the ASDR witnessed a significant yet slight decline, from 66.59 per 100,000 people (95 % UI: 63–69.73) in 1990 to

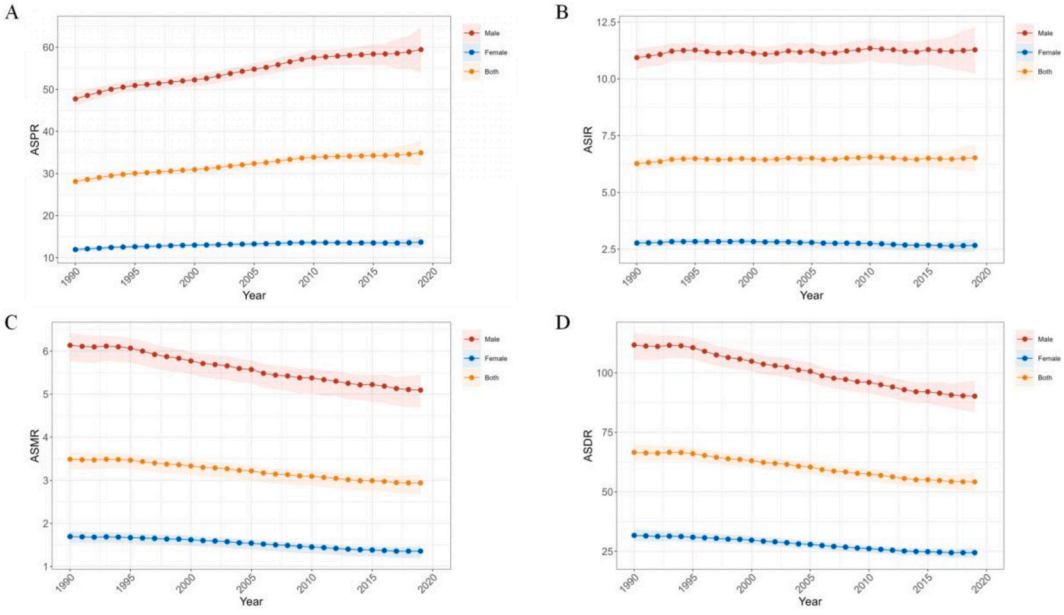

Fig. 1. The age-standardized rates of prevalence, incidence, DALY and death change curves for BCa patients from 1990 to 2019. (A) The change curve of the ASPR. (B) The change curve of the ASIR. (C) The change curve of the ASMRs for BCa patients. (D) The change curve of the ASDRs. BCa: bladder cancer; ASPR: age-standardized prevalence rate; ASIR: age-standardized incidence rate; DALY: disability-adjusted life-year; ASMR: age-standardized mortality rate; ASDR: age-standardized disability-adjusted life-years rate.

54.2 per 100,000 people (95 % UI: 50.35–57.97) in 2019. Despite this decline in the standardized rate, the total number of DALYs associated with BCa escalated substantially, from 2.567 million (95 % UI: 2.429–2.691) in 1990 to 4.393 million (95 % UI: 4.09–4.703) in 2019, marking an increase of 71.1 %. In summary, the period from 1990 to 2019 witnessed a clear upward trend in the prevalence and incidence of BCa, both in absolute numbers and when age-standardized. Conversely, there was a downward trend in mortality and disability rates when standardized by age, despite an increase in the absolute numbers of deaths and DALYs. This comprehensive analysis underscores the evolving epidemiological landscape of BCa over the past three decades.

3.2. Global burden of BCa attributable to smoking in 2019

In the period from 1990 to 2019, there was a notable increase in the global and regional burdens of BCa attributable to smoking, with few exceptions, as detailed in Supplementary Table S2. In 2019 specifically, smoking was a significant contributing factor to BCa worldwide, accounting for approximately 1.615 million (95%UI: 1.249–1.981) DALYs, and 0.078 million (95%UI: 0.058–0.097) deaths.

A comparative analysis between the years 1990 and 2019 reveals a decrease in the proportion of BCa burden attributable to smoking. In 1990, smoking was responsible for 41 % (95%UI: 32%–49 %) of total BCa deaths and 43 % (95%UI: 34%–50 %) of total DALYs. However, by 2019, these proportions had declined to 34 % (95%UI: 26%–42 %) for total deaths and 37 % (95%UI: 28%–44 %) for total DALYs (Fig. 2). This observed reduction in both the proportion of deaths and DALYs due to BCa resulting from smoking highlights a potentially positive shift in public health outcomes over the three-decade span.

3.3. Temporal trends in the BCa burden attributable to smoking

Since 1990, there has been a significant decrease in the DALYs and death rates due to BCa caused by smoking. During the period from 1990 to 1994, the ASDR for BCa showed a moderate yet consistent annual decline of 0.34 % (Annual Percent Change, APC = −0.34 %). Concurrently, ASDR exhibited a similar, albeit slight, downward trend (APC = −0.35 %). However, between 1994 and 2015, both the ASDR and ASMR experienced an accelerated decrease, with the APCs reaching −1.47 % and −1.44 %, respectively. In the more recent period, from 2015 to 2019, the decline in the ASDR and ASMR for BCa slightly decelerated, with the APCs recorded at −0.85 % and −0.88 %, respectively (Fig. 3).

3.4. Age- and sex-specific BCa burden attributable to smoking

Fig. 4A and B illustrates that individuals aged 50–74 years experienced the greatest burden of BCa attributable to smoking. Analyzing the trends from 1990 to 2019, a remarkable stability is observed in smoking-attributable DALYs among those aged under 49 years. In this younger demographic, the incidence of deaths due to BCa showed only minor fluctuations over the three decades. Conversely, in other age groups, there was a pronounced increase in both the DALYs and deaths attributable to smoking since 1990.

A detailed subgroup analysis based on sex reveals notable disparities in the impact of smoking on BCa. The total burden, encompassing both DALYs and deaths, was consistently higher in males compared to females. Additionally, distinct patterns emerged in the distribution of these burdens across various age groups when comparing the two sexes, as depicted in Fig. 4C and D. For males, the rate of DALYs associated with smoking and BCa escalated progressively with age, reaching a peak in the 85–89 years group before exhibiting a subsequent decline. This trend was mirrored in females, with a similar age-related increase and peak. However, the peak in death rates due to BCa associated with smoking presented later in life for both sexes. Among males, the peak was observed in those aged over 95 years, followed by a decrease. The female death rate also escalated with advancing age, with the highest rates recorded in

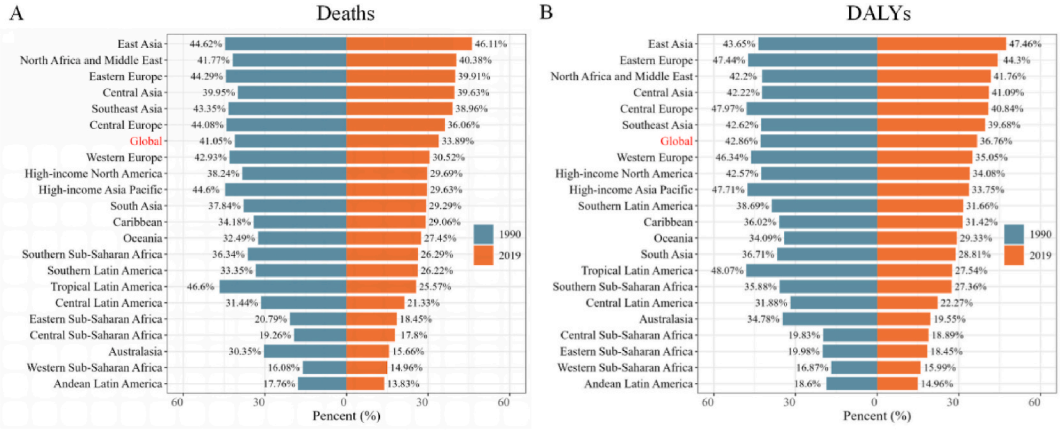

Fig. 2. The proportion of BCa deaths and DALYs attributable to smoking globally and in 21 GBD regions in 1990 and 2019. BCa: bladder cancer; DALYs: disability-adjusted life-years; GBD: Global Burden of Disease.

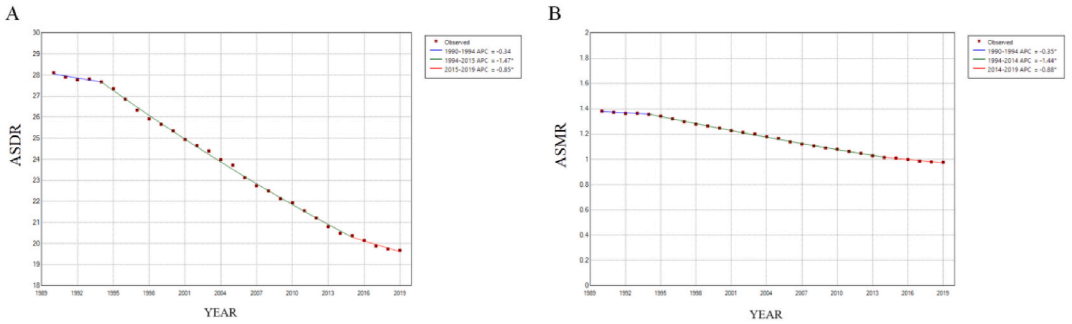

Fig. 3. The temporal changes in the global burdens of BCa caused by smoking from 1990 to 2019 for all ages and both sexes combined. (A) The ASDRs of BCa attributable to smoking. Final Selected Model: 2 Joinpoints. (B) The ASMRs of BCa attributable to smoking. Final Selected Model: 2 Joinpoints. * indicates that the APC is significantly different from zero at the alpha 0.05 level. BCa: bladder cancer; ASDR: age-standardized disability-adjusted life-years rate; ASMR: age-standardized mortality rate; APC: annual percent change.

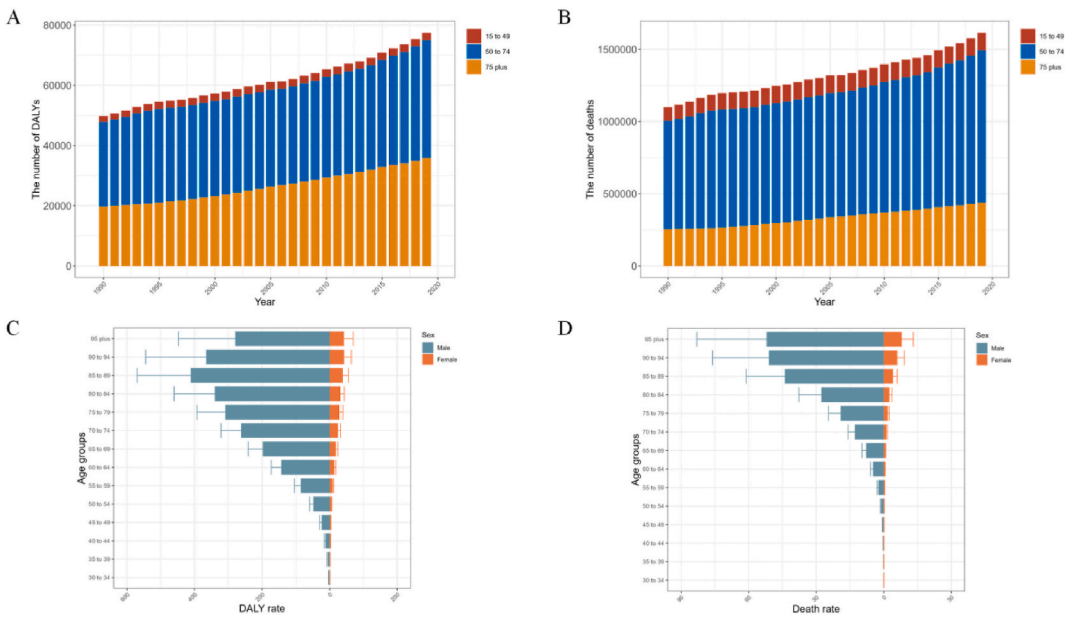

Fig. 4. The burdens of BCa caused by smoking among various age groups and genders in 2019. (A) The DALYs cases of BCa attributable to smoking. (B) The death cases of BCa attributable to smoking. (C) DALYs rates. (D) Death rates. BCa: Bladder cancer; DALY: disability adjusted life-year.

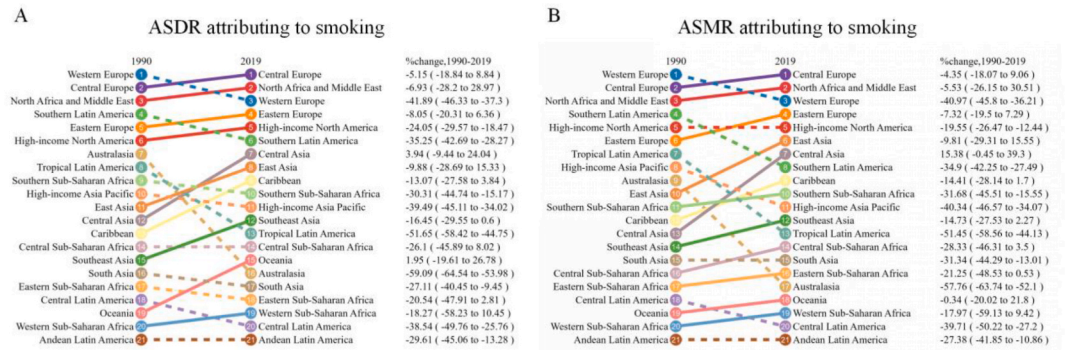

Fig. 5. The ranking changes of burden in BCa attributable to smoking for both sexes combined for all ages in 21 Global Burden of Disease regions from 1990 to 2019. (**A**) The ranking changes of the ASDRs of BCa attributable to smoking. (B) The ranking changes of the ASMRs of BCa attributable to smoking. BCa: Bladder cancer; ASDR: age-standardized disability-adjusted life-years rate; ASMR: age-standardized mortality rate.

individuals aged over 95 years.

3.5. Regional and national BCa burdens attributable to smoking

Regionally, Western Europe had the highest ASDRs and ASMRs attributable to smoking in 1990 and Central Europe in 2019 (Fig. 5 and Supplementary Table S1). In addition, Western Sub-Saharan Africa and Andean Latin America had the lowest ASDRs and ASMRs in 1990 and 2019, respectively. The largest increase in the ASDRs and ASMRs occurred in Central Asia from 1990 to 2019, with an increase of ~3.94 % and ~15.38 %, respectively. The largest decrease in the ASDRs and ASMRs occurred in Australasia from 1990 to 2019, with a decrease of ~59.09 % and ~57.76 %, respectively.

In the analysis of sex-specific trends across the 21 GBD regions, notable disparities in the burden of BCa attributable to smoking emerged in 2019 (Fig. 6). Central Europe exhibited the highest ASDRs and ASMRs among males and the highest ASDRs in females. Females in high-income North America had the highest ASMRs.Conversely, Andean Latin America reported the lowest male ASDRs and ASMRs, while the lowest female ASDRs and ASMRs was observed in Central Asia.

Over the past three decades, significant regional variations were evident in the changes in ASDRs (Fig. 6 and Supplementary Table S3). The most substantial increase in ASDRs for males was seen in Central Asia, whereas Eastern Europe experienced the largest increase in female ASDRs. In contrast, Australasia demonstrated the most pronounced decrease in ASDRs for both sexes. With respect to changes in the ASMR, the greatest exacerbations in males were identified in Central Asia and in females in Eastern Europe. Conversely, the most notable improvements were observed in Australasia for males and in East Asia for females.

In a comparative analysis of the 204 nations and territories, Lebanon emerged with the highest ASDRs and ASMRs of BCa attributable to smoking in both 1990 and 2019, surpassing other regions (Fig. 7 and Supplementary Table S4). Conversely, Nigeria reported the lowest ASDRs and ASMRs in 2019, indicating regional variations in the impact of smoking on BCa.

Notably, Cabo Verde experienced the most pronounced increase in the ASDRs of BCa attributable to smoking over the past three decades. This trend was paralleled by a similar escalation in the ASMR, positioning Cabo Verde as the region with the largest increase among the 204 regions, as detailed in Supplementary Table S4. In stark contrast, Singapore demonstrated the most substantial reduction in both the ASDR and ASMR, underscoring the effectiveness of its public health initiatives and smoking cessation programs.

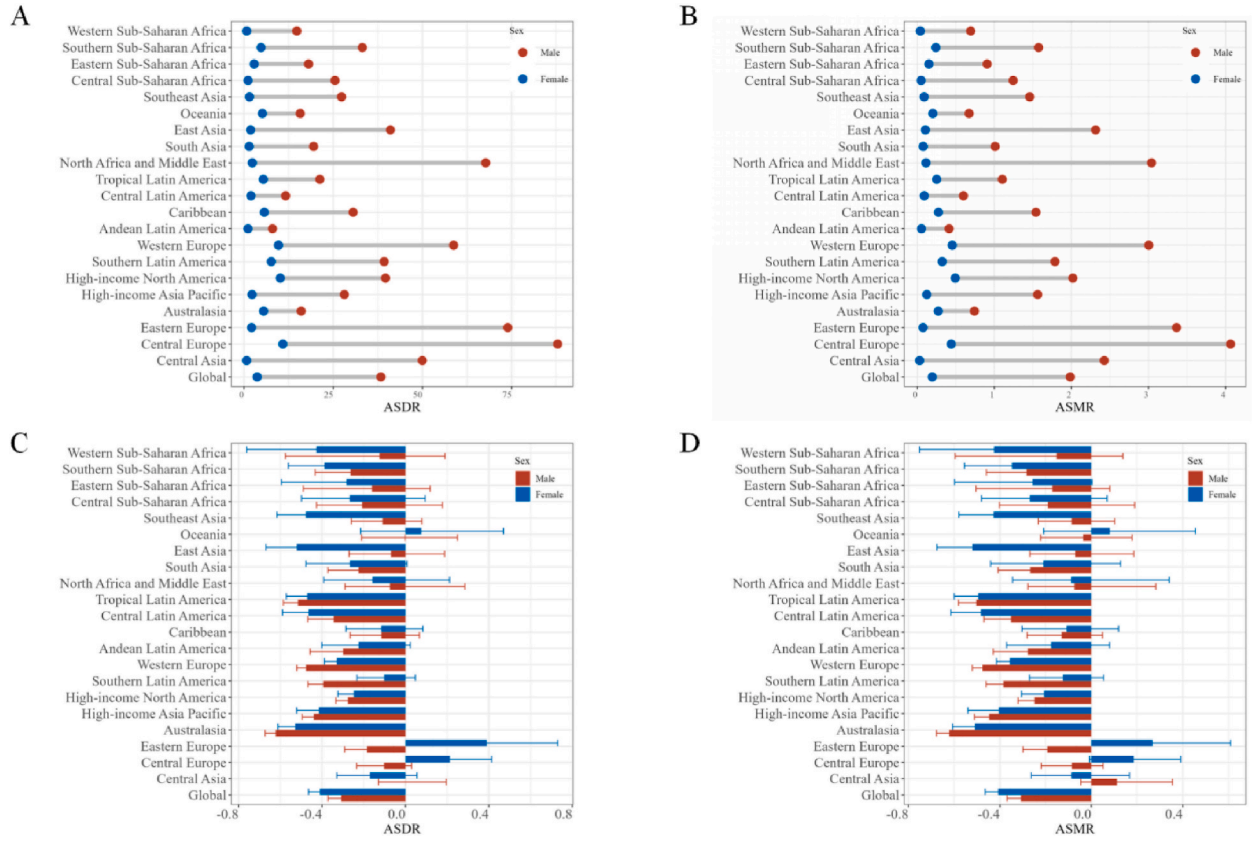

Fig. 6. The burdens of BCa caused by smoking in 2019 and their percentage changes in rates from 1990 to 2019 across 21 GBD regions among various genders. (A) ASDRs of BCa caused by smoking. (B) ASMRs of BCa caused by smoking. (C) Percentage changes in ASDRs caused by smoking from 1990 to 2019. (D) Percentage changes in ASMRs caused by smoking from 1990 to 2019. BCa: Bladder cancer; GBD: global burden of disease; ASDR: age-standardized disability-adjusted life-years rate; ASMR: age-standardized mortality rate.

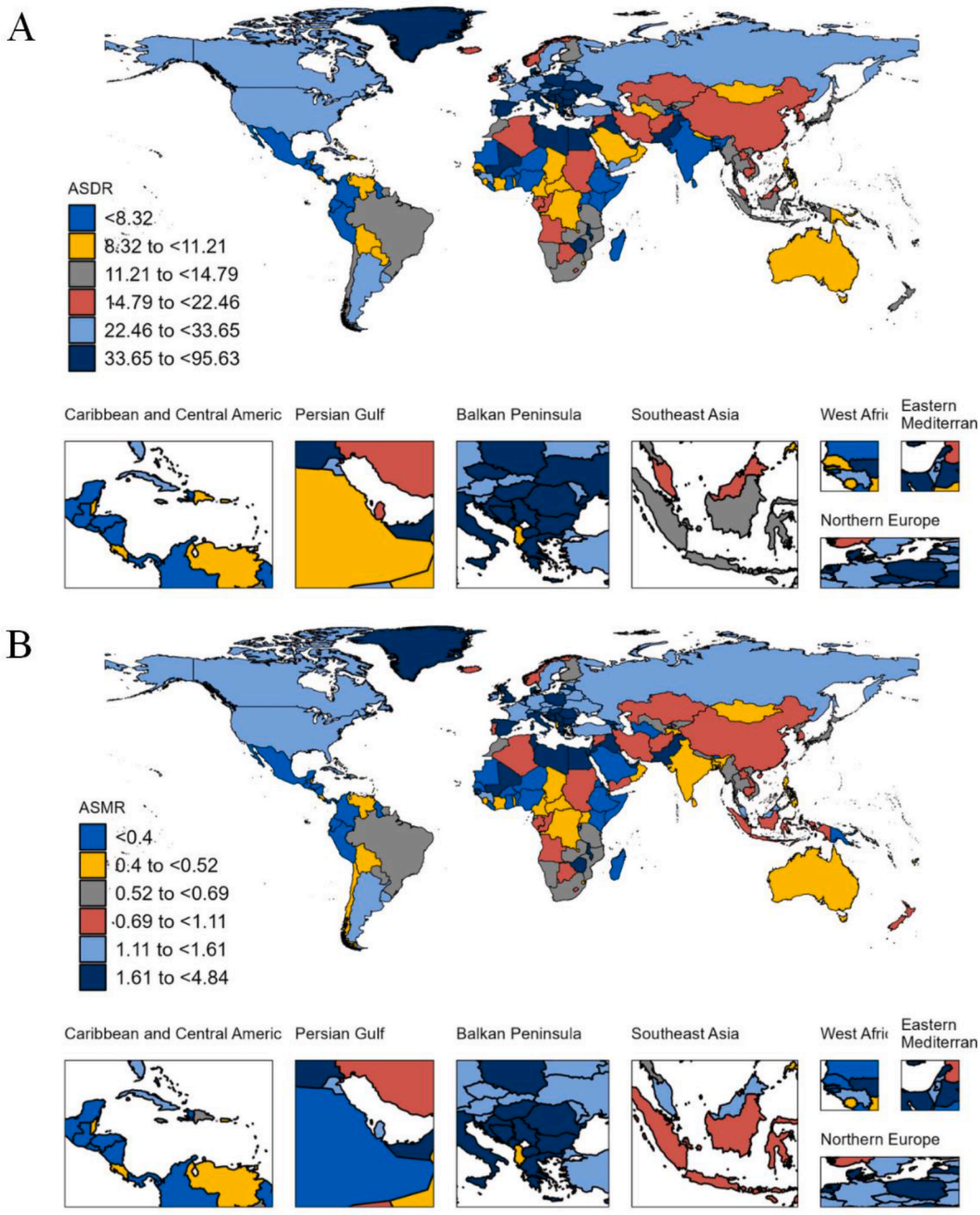

Fig. 7. The burdens of BCa associated with smoking among 204 countries and territories in 2019. (A) ASDRs of BCa associated with smoking. (B) ASMRs of BCa associated with smoking. BCa: Bladder cancer; ASDR: age-standardized disability-adjusted life-years rate; ASMR: age-standardized mortality rate.

3.6. Association of BCa burden attributable to smoking and the SDI

Within the global context of 2019, the relationship between the SDI and both the ASDRs and ASMRs of smoking related BCa exhibited a pronounced specific nonlinear trends (Fig. 8). The inflection point of this trend was notably situated at an SDI value of approximately 0.5. Below this SDI threshold, both the ASDRs and ASMRs demonstrated a gradual increasing trend. As SDI ranged between 0.5 and 0.6, the escalation of the ASDRs and ASMRs entered a plateau phase. Subsequently, with an SDI greater than 0.6, there was a marked acceleration in the rise of both the ASDRs and ASMRs. The ascent continued until the SDI reached a level of ~0.72, at which both rates achieved their relative peaks, suggesting that the apex of mortality and disability burden due to BCa occurs at this

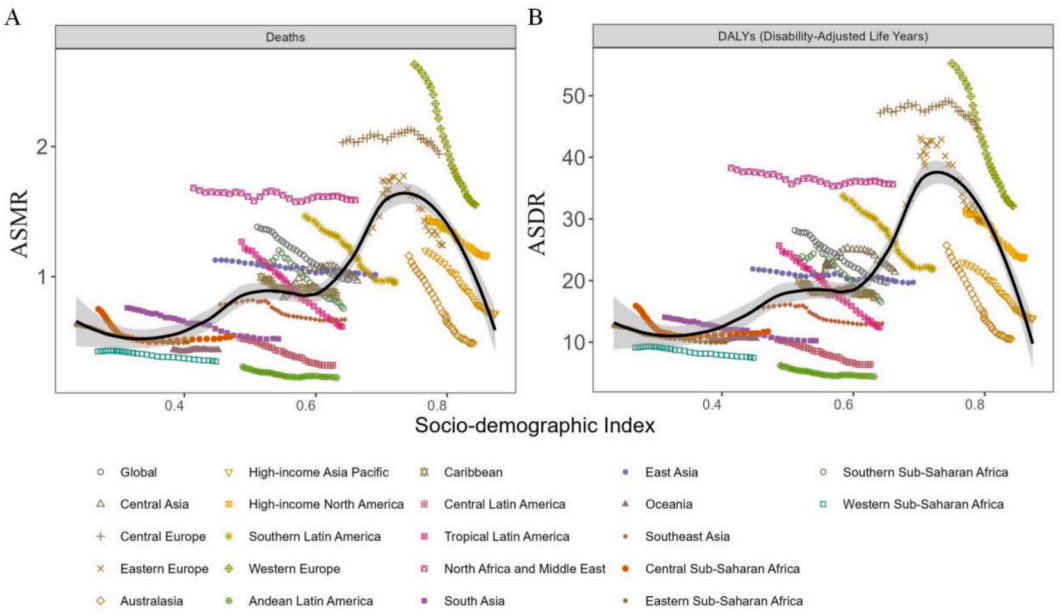

Fig. 8. The relationships between the SDI and the BCa burdens related to smoking among the 21 GBD regions employed by Pearson correlation test. (A) The association between ASMRs of BCa related to smoking and SDI among 21 GBD regions. (B) The association between the ASDRs of BCa related to smoking and SDI among 21 GBD regions. BCa: Bladder cancer; SDI: socio-demographic index; GBD: global burden of disease; ASDR: age-standardized disability-adjusted life-years rate; ASMR: age-standardized mortality rate.

high-middle level of SDI. Conversely, surpassing the SDI threshold of ~0.72, a significant decline in both the ASDRs and ASMRs was observed.

In addition, We adopted Radial Basis kernel function as kernel function, and used Gaussian process regression model to analyze the

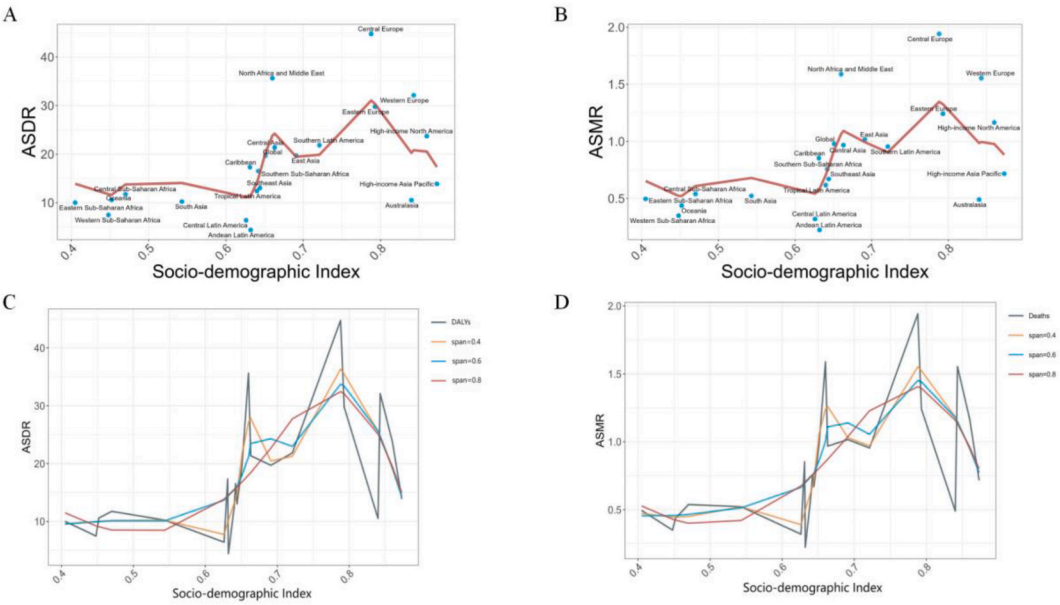

Fig. 9. The relationships between the SDI and the BCa burdens related to smoking among the 21 GBD regions employed by Gaussian process regression model and the Loess smoother. (A) The association between ASDRs of BCa related to smoking and SDI among the 21 GBD regions employed by Gaussian process regression model. (B) The association between the ASMRs of BCa related to smoking and SDI the 21 GBD regions employed by Gaussian process regression model. (C) The association between the ASDRs of BCa related to smoking and SDI among the 21 GBD regions employed by the Loess smoother. (D) The association between the ASMRs of BCa related to smoking and SDI among the 21 GBD regions employed by the Loess smoother. BCa: Bladder cancer; SDI: socio-demographic index; GBD: global burden of disease; ASDR: age-standardized disability-adjusted life-years rate; ASMR: age-standardized mortality rate.

regression relationship between SDI and both the ASDRs and ASMRs of smoking related BCa. The fitted regression curves were shown in Fig. 9A and B, and the hyperparameters sigma were 38.66 and 21.60 respectively. Three smooth curves were obtained by Loess with three different parameters α, as shown in Fig. 9C and D. The overall trend was consistent with our previous Pearson correlation test, showing an increase in low SDI to high-middle SDI and a decrease in high SDI. Spearman rank order correlation tests were used to calculate correlation coefficients of 0.6917 and 0.6646, respectively, with p values less than 0.001, indicating that the correlation between SDI and both the ASDRs and ASMRs of smoking related BCa was statistically significant.

4. Discussion

BCa persists as a critical global health concern, with its prevalence escalating annually. Despite a heterogeneous trend in incidence rates worldwide, specific regions have observed notable increases in both incidence and mortality. Our review of literature from 1990 to 2019 underscores a detailed portrayal of BCa's burden but also reveals a scant analysis of associated risk factors [18]. The undeniable link between smoking and BCa—nearly half of all cases—are precipitated by tobacco use, emphasizing external factors over genetic predispositions [19,20]. According to the International Agency for Research on Cancer, primary risks for BCa include smoking, occupational exposures, and environmental elements [21].

The declining global prevalence of smoking contrasts with the stubbornly high total number of smokers, illustrating the complex epidemiology of tobacco usage worldwide. In 2019, approximately 1.133 billion (940 million males and 193 million females aged 15 or older) individuals were active smokers, with a significant presence in regions of medium to very high Human Development Index (HDI) levels [9]. This distribution highlights a nuanced pattern of tobacco consumption influenced by economic growth, strategic marketing by the tobacco industry, and varying stages of public health initiatives.

Our study, leveraging data from the Global Burden of Disease Study 2019, maps the intricate landscape of smoking-related BCa over the past three decades. Previous studies reveals an increase in age-standardized prevalence rates and absolute case numbers, with projections indicating a continued rise into 2040 [22]. Contrarily, ASDRs and ASMRs have trended downwards, attributed to the declining prevalence of smoking and improvements in BCa management [8,23]. Nevertheless, the growing absolute numbers of BCa-related deaths and DALYs highlight an enduring health challenge.

In our demographic-specific findings, males aged 50–74 emerge as the most burdened group, with increasing DALYs and mortality annually. The susceptibility of this demographic to BCa, compounded by smoking duration and frequency, is a critical concern. A longitudinal cohort study spanning three decades underscores that smoking elevates BCa risk by 2–3 times, with every additional decade of smoking increasing the risk by approximately 1.5–2 times [19,24]. Furthermore, the global trend towards an aging population is a significant factor. Previous research has demonstrated that the rate of smoking-related BCa decreases over time post-cessation. However, former smokers still face higher risks compared to never-smokers even after 30 years of cessation [25]. This underscores the long-term impact of smoking on BCa risk and emphasizes the need for continued vigilance and public health strategies to manage smoking as a modifiable risk factor.

Regional disparities in BCa burden are pronounced, with the highest ASDRs and ASMRs in the Western Europe in 1990 and Central Europe in 2019. In contrast, Western Sub-Saharan Africa and Andean Latin America had the lowest ASDRs and ASMRs in 1990 and 2019, respectively. Such disparities underscore the influence of socioeconomic factors, including lifestyle, healthcare access, and environmental exposures, on health outcomes. Our study confirms that the SDI is a critical determinant of health disparities. As countries transition from low to high-middle SDI, BCa burden increases initially with ASDR and ASMR due to increased longevity and high smoking prevalence associated with economic development, but decreases at high SDI levels due to effective health interventions, improved health awareness, reduced smoking prevalence, and better cancer detection and treatment. The lowest burden observed in the regions with the highest SDI supports the hypothesis that socioeconomic factors play a key role in managing the health effects of smoking. These trends highlight the complex interactions between socioeconomic development and disease burden, highlighting the need for targeted strategies in public health planning and resource allocation to address the challenge of smoking-related BCa.

Notably, Australasia exemplifies significant progress in managing smoking-related BCa burdens, achieved through rigorous tobacco control measures. Australasia has achieved the greatest improvement in the burden of BCa attributable to smoking among the GBD 21 regions between 1990 and 2019, with Australia providing a case study for its remarkable progress in tobacco control. Stringent legislation, combined with educational campaigns, has halved smoking rates since 1990 [26,27]. The country's comprehensive approach includes progressive taxation, widespread public health campaigns, and pioneering plain packaging laws, all contributing to the decline in smoking-related DALYs and mortality [28]. This suggests that areas with slower progress in reducing smoking-related BCa burdens should consider adopting similar policies and strategies.

The improvement in the burden of BCa attributable to smoking in Singapore is also impressive. Singapore, one of the first 40 countries to ratify the Framework Convention on Tobacco Control, has strict smoking policies and extensive regulations on the supply and demand for tobacco [29]. It has a strong track record of taking anti-tobacco measures, including designation of smoke-free public places and transport, bans on advertising, promotion and sponsorship, and enforcement of strict regulations on packaging and labelling of tobacco products [30]. The city-state also recently raised the minimum legal age (MLA) for purchasing or consuming conventional cigarettes to 21 years. To discourage youth smoking, as many underage smokers report obtaining cigarettes from older peers [31,32], Khoo et al. recommend further expansion of the MLA policy to create a "smoke-free generation" (SFG) starting with the 2000 birth cohort [33].

Acknowledging the limitations of our study, including data quality concerns and potential biases in the GBD methodology, we emphasize the necessity for improved data collection and the adaptation of cancer-related diagnostics. The varied implementation of tobacco control across countries poses challenges in correlating our findings with specific smoking interventions. The emergence of

new nicotine delivery systems has added to the complexity of the situation, making it necessary that future studies should focus on longitudinal studies to gain insights into the long-term effects of smoking on BCa risk, as well as the impact of emerging tobacco products. In addition, more research is needed to understand the interaction of genetic predisposition and environmental risk factors in the pathogenesis of BCa.

In conclusion, our study accentuates the significant role of smoking in the global health burden of BCa. Despite a decrease in the proportion of smoking-related BCa burden, the absolute numbers of cases and DALYs rise, calling for vigilant action. Effective tobacco control strategies, tailored to regional and national contexts, comprehensive tobacco control, public information campaigns, and equitable access to healthcare remain vital in reducing the global burden of smoking-related BCa.

5. Conclusion

Although the proportion of smoking-related BCa burden decreased between 1990 and 2019, the absolute numbers of deaths and DALYs were still rising, requiring vigilant action. The burden of BCa caused by smoking was greater in males, middle-aged and elderly people, and people in countries with high-middle SDI. Our results highlight the need for comprehensive anti-smoking campaigns and targeted interventions in areas with a high burden of BCa associated with smoking to mitigate this increasing burden.

Ethics statement

The Ethics Review Committee of Shuguang Hospital Affiliated to Shanghai University of Traditional Chinese Medicine determined that the study did not require ethical approval and consent to participate because it used publicly available data.

Sources of funding

This work was supported by the National Natural Science Foundation of China (82174122), the Health Discipline Leader Program of Shanghai Health Commission (2022XD011), and the Promotion and Optimization Management of Diagnosis and treatment technology in Municipal Hospitals of Shanghai Shenkang Hospital Development Center (SHDC12023113).

Data availability statement

Publicly available datasets were analyzed in this study. The data can be found here: http://ghdx.healthdata.org/gbd-results-tool. The dataset(s) supporting the conclusions of this article is(are) included within the article (and its additional file(s)).

CRediT authorship contribution statement

Jixiang Yuan: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Lichen Chen:** Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Jielong Zhou:** Visualization, Software, Resources, Methodology. **Xinyue Zang:** Validation, Supervision, Software, Resources. **Tongtong Zhang:** Software, Project administration, Methodology, Investigation, Data curation. **Xiran Ju:** Visualization, Validation, Software, Conceptualization. **Mingyue Tan:** Writing – review & editing, Validation, Supervision. **Dongliang Xu:** Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that there is no conflict of interest.

Acknowledgements

This would include acknowledgments to contributors and funding sources.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e34114.

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