Global trends and regional differences in the burden of cancer attributable to secondhand smoke in 204 countries and territories, 1990-2019

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Abstract

Background: To describe the status quo and trends of the global burden of all cancers caused by secondhand smoke during 1990-2019.

Methods: Data on cancer associated with secondhand smoke were extracted from the Global Heath Data Exchange (GHDx). Cancer burden was measured by cancer-related deaths, disability-adjusted life years (DALYs), years lived with disability (YLDs), and years of life lost (YLLs). Absolute numbers and age-standardized rates (per 100,000 people) were reported for all indicators. Estimated percentage changes in age-standardized rates by age, sex, region and Socio-demographic Index (SDI) were calculated to describe the temporal trends in cancer burden.

Results: In 2019, age-standardized rates of death, DALYs, and YLLs among the cancer population globally due to secondhand smoke were 1.60, 38.54, and 37.77, respectively, the proportions of which in the total cancer burden for all risk factors combined decreased slightly from 1990 to 2003 and then increased from 2004 to 2019. In 2019, over 50% of the cancer burden was concentrated in adults aged 55-75 for men and 50-70 for women. Between 1990 and 2019, there was an increase in age-standardized rates of death, DALYs, YLDs, and YLLs among those aged 70 years or older. The age-standardized YLDs rate attributable to secondhand smoke was higher among women; it decreased in men but increased in women, causing a wider gap between the two sexes. A greater cancer burden was mainly seen in North American countries in 1990 and in European countries in 2019. Reductions in the annual rate change of cancer burden were found mainly in North America and Oceania, while increases were found in Africa and Asia. In 2019, high-middle SDI countries and middle SDI countries had higher age-standardized rates of deaths, DALYs, YLDs and YLLs than the global level. During 1990 and 2019, the largest decline in cancer burden was seen in high SDI countries, while middle or lower SDI countries experienced increases in all age-standardized rates.

Conclusion: Cancer burden attributable to secondhand smoke is concerning given the increasing health loss and differences in the distribution of cancer burden worldwide. Further studies are needed to investigate the causes of disparities in cancer burden attributable to secondhand smoke and to improve understanding of the contribution of secondhand smoke to the burden of different types of cancer.

Trial registration: Retrospectively registered.

Introduction

Cancer is widely regarded as a global health threat that contributed to approximately 10 million deaths in 2020 and nearly one in six deaths.[1] It is estimated that the annual number of new cancer cases will be up to 21.6 million by 2030,[2] causing a great global cancer burden that varies remarkably across countries and territories. In particular, new cases and deaths of cancer have been substantially increasing in low- and middle-income countries (LMICs) because of aging and the increased prevalence of other risk factors, and more than 70% of cancer deaths are expected to occur in Africa by 2030.[3] This pattern poses challenges for achieving the targets specified in the United Nations (UN) Agenda for Sustainable Development to reduce one-third premature mortality from cancer and other non-communicable diseases (NCDs) by 2030. [2] Nevertheless, many efforts have been made to reduce the risk and disability from cancer. For example, the World Health Organization (WHO) collaborated with Member States to develop the National Cancer Control Plan and launched the WHO Global

Action Plan for the Prevention and Control of NCDs 2013–2020, which set a 30% reduction in tobacco use by 2025 as one of six targets.[2]

It is noteworthy that cancer prevention and control not only rely on high-quality clinical interventions but also require effective risk management. According to a report by the World Health Organization (WHO), approximately 30–50% of cancers can currently be prevented by avoiding risk factors for cancer and implementing existing evidence-based prevention strategies.[3] In addition, exposure to modifiable risks, such as tobacco use, alcohol consumption, unhealthy diet, physical inactivity and air pollution, is directly associated with cancer treatment and prognosis, such as poor therapeutic response rate, increased recurrence, and therapy complications.[4] Smoking or tobacco use is well known as a leading cause of cancer and cancer death, accounting for approximately 25% of cancer deaths worldwide.[3] It is reported that tobacco smoke contains more than 7,000 chemicals, at least 70 of which are known to cause cancer by damaging DNA.[5] Smoking commonly includes active smoking and passive smoking, both of which increase the risk of cancer.

Passive smoking, which is also known as secondhand smoking, could significantly increase the risk of many types of cancers, including breast cancer, nasal sinus cavity cancer, and nasopharyngeal cancer in adults, and the risk of leukemia, lymphoma, and brain tumors in children.[5,6] According to a meta-analysis, secondhand smoke could increase the risk of cancer development by 16% compared to those who were not exposed to secondhand smoke. [5] Studies on the relationship between secondhand smoke and cancer found that secondhand smoke contributed to 1.8% of cancer deaths among men and 50% among women in China.[7,8] This evidence shows that secondhand smoking poses considerable challenges to reducing cancer burden throughout the world.

Exploring the risk factors and interventions for cancers has been a primary concern of healthcare providers as well as researchers, yet the cancer burden caused by secondhand smoke is not well understood for the following reasons. First, there was no study to estimate the global burden of cancer attributable to secondhand smoke and analyze the contribution of cancer burden caused by secondhand smoke to the total cancer burden at the global level.[9] Second, although a meta-analysis was performed to evaluate cancer risk associated with secondhand smoking across all cancers,[5] there was a lack of data related to disability-adjusted life-years (DALYs), years lived with disability (YLDs), and years of life lost (YLLs) of cancer patients exposed to secondhand smoke. Third, existing studies mainly focused on lung cancer, breast cancer and secondhand smoking,[10–12] or on the influence of parental smoking on the development of cancers in children,[13,14] rather than among the whole cancer population. Fourth, several studies were conducted to explore the association of cancer and secondhand smoking in different countries, for instance, in China,[7,8,15] Germany,[16] and Korea[17]. Additionally, disparities in cancer burden attributable to secondhand smoke across sexes, regions and countries with different socioeconomic status cannot be obtained from these studies.

To fill these gaps, this study aimed to investigate the burden of cancer attributable to secondhand smoke by age, sex, sociodemographic index (SDI) for 204 countries and territories between 1990 and 2019, drawing data from the dataset of Global Health Data Exchange (GHDx) supported by the IHME.

Methods

Data source

The data were extracted from the GHDx database (https://ghdx.healthdata.org), which is a data catalog created and supported by IHME, an independent population health research organization based at the University of Washington School of Medicine. GHDx provides the data and results from the Global Burden of Disease (GBD) studies that have been initiated by IHME since 2002. GBD studies collect and extract data from national and subnational censuses and representative major survey series, such as the Demographic and Health Survey and the Multiple Indicator Cluster Surveys.[18] The GBD team of researchers incorporates data from a large number and wide variety of sources to estimate mortality, causes of death and illness, and risk factors. The GHDx includes data for causes, risks, cause-risk attribution, etiologies, and impairments, which can be chosen from a selection box and downloaded for further analysis. The data elements recruited into this study include indicators (deaths, YLLs, YLDs, and DALYs), locations, age (all ages, age-standardized), sex, cause of cancer (total cancers), and risk (secondhand smoke).

Estimation framework

Geographical units, age groups, and time periods

For this study, the data were presented at four levels: global, demographic, regional, and Socio-Demographic Index (SDI). At the global level, the data were analyzed for all ages and both sexes. At the demographic level, the data were evaluated by age and sex. At the regional level, the data were estimated for all ages and both sexes combined by seven continents, including Asia, Africa, North America, South America, Europe and Oceania. The SDI is a composite measure to classify socioeconomic development status by measuring lag-distributed income per person, average years of schooling in the population over 15 years old, and total fertility rate in the population under 25 years old. It is a geometric mean of 0 to 1, indicating that a country with a higher SDI would have a higher level of sociodemographic development related to health outcomes.[18] At the SDI level, the data were demonstrated according to five predefined SDI groups, including high SDI (0.81-1.0), high-middle SDI (0.69–0.81), middle SDI (0.61–0.69), low-middle SDI (0.46–0.61), and low SDI (0-0.46).[18] Estimation of the data was performed every year from 1990 to 2019.

Estimate of secondhand smoke exposure

This study applied the definition of secondhand smoke exposure used by GBD 2019, according to which exposure to secondhand smoke refers to current exposure to secondhand tobacco smoke at home, at work, or in other public places.[17] Only non-smokers are taken into consideration when estimating secondhand smoke exposure. Non-smokers refer to people who are not daily smokers, including former smokers, occasional smokers, and ever non-smokers. Both children and adults are evaluated for exposure. The study data on exposure to secondhand smoke analyzed were secondary data from GBD 2019.

Estimate of cancer burden

GHDx provides data on 30 cancer categories that are classified according to the International Statistical Classification of Disease and Related Health Problem, Tenth Revision (ICD-10), including all benign and in situ neoplasms (cancer types included in the study can be found in the supplementary). To estimate the total cancer burden attributable to secondhand smoke, the data were used for all types of cancers combined. Indicators measuring cancer burden were deaths, DALYs, YLDs, and YLLs. DALYs are the sum of YLDs and YLLs. YLDs refer to the number of life years a person lives with disability due to cancer. YLLs refer to the number of life years a person loses as a result of dying early caused by cancer.[19]

Statistical analysis

The numbers and rates of deaths, DALYs, YLDs, and YLLs were used to describe the status quo and trend of cancer burden. All the numbers were expressed as absolute numbers, while all the rates were expressed as age-standardized rates (per 100,000 people) based on the GBD reference population. To examine the temporal trends, we estimated the percentage change in the age-standardized rates from 1990 through 2004 (the first half of the study period) and 2005 through 2019 (the second half of the study period). A nonparametric test was used to determine if there were statistically significant differences, while the Mann–Whitney U test was for unpaired groups, and the Kruskal–Wallis H test was for more than two groups. In this study, the 95% uncertainty interval (UI) was reported for all estimates. Analyses were completed using SPSS Version 27.0 (IBM Corp., Armonk, N.Y., USA). A P value less than 0.05 was considered statistically significant.

Results

Cancer burden attributable to secondhand smoke at the global level

Secondhand smoke moved from the 11th leading risk of cancer DALYs in 1990 to tenth place in 2019. For those younger than 70 years, secondhand smoke was in the top ten risk of cancer DALYs. Compared to 1990, most age groups (aged between 25 and 34 years; aged 50 years or older) experienced an increase in rank (Table 1).

Table 1
Ranking of age-specific global DALYs for all cancers attributable to secondhand smoke in 1990 and 2019

	1990 Rank	2019 Rank	Change of rank
Age-standardized	11	10	+ 1
25–29	9	8	+ 1
30–34	10	9	+ 1
35–39	8	9	-1
40–44	8	10	-2
45–49	8	9	-1
50–54	8	7	+ 1
55–59	9	7	+ 2
60–64	10	7	+ 3
65–69	11	10	+ 1
70–74	12	11	+ 1
75–79	14	12	+ 2
≥ 80	16	13	+ 3

There were 0.13 million (95% UI: 0.08 to 0.19) deaths among the cancer population worldwide due to secondhand smoke and 3.22 million (95% UI: 2.07 to 4.63) DALYs, of which 2% came from YLDs and 98% from YLLs in 2019 (Table 2). Between 1990 and 2019, the absolute numbers of deaths, DALYs, YLDs and YLLs significantly increased by 77.83% (95% UI: 59.34 to 96.49, $p < 0.001$), 58.48% (95% UI: 42.41 to 75.43, $p < 0.001$), 107.01% (95% UI: 85.38 to 128.01, $p < 0.001$) and 57.73% (95% UI: 41.75 to 74.92, $p < 0.001$), respectively. However, age-standardized rates of cancer-related deaths, DALYs and YLLs attributable to secondhand smoke were significantly reduced from 1.84 to 1.60 ($p < 0.001$), from 48.49 to 38.54 ($p < 0.001$), and from 47.74 to 37.77 ($p < 0.001$), respectively (Table 2). Annual changes in absolute numbers and age-standardized rates are shown in Fig. 1. On the basis of this figure, the absolute numbers of deaths, DALYs and YLLs increased consecutively, whereas the age-standardized rates significantly decreased, except for YLDs, between 1990 and 2019 (Fig. 1).

Table 2
Global cancer burden attributable to secondhand smoke for both sexes combined in 1990 and 2019

	Absolute number		**Percentage change in absolute number (%)**	***p***	**Age-standardized rate**		**Percentage change in age-standardized rate (%)**	***p***
	1990	**2019**			**1990**	**2019**		
Deaths	73382.33 (48515.13, 105076.31)	130497.72 (82600.70, 189503.61)	77.83 (59.34, 96.49)	< 0.001	1.84 (2.63, 1.21)	1.60 (1.01, 2.32)	-13.38 (-22.26, -4.32)	< 0.001
DALYs	2032715.41 (1349038.10, 2888829.75)	3221523.19 (2069953.29, 4632379.11)	58.48 (42.41, 75.43)	< 0.001	48.49 (69.09, 32,24)	38.54 (24.77, 55.49)	-20.51 (-28.51, -12.23)	< 0.001
YLDs	30985.71 (17086.07, 48417.67)	64144.93 (33735.98, 100385.84)	107.01 (85.38, 128.01)	< 0.001	0.75 (1.16, 0.42)	0.77 (0.41, 1.20)	3.03 (-7.89, 13.87)	0.31
YLLs	2001729.69 (1332659.92, 2856719.97)	3157378.26 (2016778.65, 4549753.08)	57.73 (41.75, 74.92)	< 0.001	47.74 (68.14, 31.79)	37.77 (24.12, 54.49)	-20.88 (-28.92, -12.41)	< 0.001

Note: 1. Data in parentheses are 95% uncertainty intervals; 2. Age-standardized rates (per 100,000 people) based on GBD reference population.

Among the total cancer burden for all risk factors combined, secondhand smoke was responsible for 2.91% (95% UI: 2.04 to 3.81) deaths, 3.05% (95% UI: 2.17 to 3.97) DALYs, 2.34% (95% UI: 1.68 to 2.75) YLDs and 3.07% (95% UI: 2.17 to 4.00) YLLs in 2019. Within the first half of the study period (1990–2004), the proportion of cancer burden attributable to secondhand smoke in the total cancer burden for all risk factors combined significantly decreased in terms of cancer deaths, DALYs, YLDs and YLLs. However, during the second half of the study period (2005–2019), the proportions of cancer deaths, DALYs, and YLLs attributable to secondhand smoke increased significantly (Table 3). The annual change in the proportion of cancer burden due to secondhand smoke in the total cancer burden that was caused by all risk factors is shown in Fig. 2. In general, the contribution of the cancer

burden decreased slightly from 1990 to 2003 and then increased from 2004, especially in terms of deaths, DALYs and YLLs (Fig. 2).

Table 3
Contribution of cancer burden caused by secondhand smoke to total cancer burden caused by all risk factors for both sexes between 1990 and 2019

	Proportion* (%)		Change in proportion (%)					
	1990	2019	1990–2004	*P*	2005–2019	*P*	1990–2019	*P*
Deaths	2.83 (2.02, 3.67)	2.91 (2.04, 3.81)	-3.11 (-5.31, -2.65)	< 0.001	5.96 (5.63, 6.83)	< 0.001	2.75 (1.20, 3.60)	0.004
DALYs	3.06 (2.19, 3.97)	3.05 (2.17, 3.97)	-3.85 (-6.36, -4.25)	< 0.001	3.95 (3.59, 4.18)	< 0.001	-0.09 (-1.15, -0.13)	0.67
YLDs	2.41 (1.84, 2.94)	2.34 (1.68, 2.75)	-4.98 (-6.66, -5.57)	< 0.001	2.21 (-2.02, -1.03)	0.01	-3.20 (-8.61, -6.44)	< 0.001
YLLs	3.07 (2.20, 3.99)	3.07 (2.17, 4.00)	-3.77 (-5.71, -3.88)	< 0.001	4.07 (3.57, 4.51)	< 0.001	0.12 (-0.56, 0.33)	0.93

Note: Data in parentheses are 95% uncertainty intervals.

*Proportion is calculated by dividing the age-standardized rates of cancer burden attributable to secondhand smoke by the age-standardized rates of total cancer burden caused by all risk factors.

Cancer burden attributable to secondhand smoke by age and sex

Figure 3 shows the age-specific distribution of cancer burden attributable to secondhand smoke by sex in 2019. Overall, absolute numbers and age-standardized rates of deaths, DALYs, and YLLs were higher in women until age 60 years, after which they became higher in men. For cancer deaths, age-standardized mortality increased consecutively with age in both sexes. For DALYs and YLLs, among men, the proportion of absolute numbers was higher in those aged between 55 and 75 years, accounting for 64.73% of DALYs and 53.94% of YLLs; among women, the proportion of absolute numbers was higher in those aged between 50 and 70 years, accounting for 64.29% of DALYs and 54.01% of YLLs. Absolute YLDs number was larger in every age group among women than men; the age-standardized YLDs rate was significantly higher in women under the age of 75 years (Fig. 3).

In terms of the age differences in global change in cancer burden attributable to secondhand smoke in 1990 and 2019, age-standardized rates of deaths, DALYs, YLDs and YLLs decreased among most age groups. There was an increase in age-standardized mortality among those aged 80 years or older, in the age-standardized DALYs rate and YLLs rate among those aged 75 years or older, and in the age-standardized YLDs rate among those 70 years or older (Fig. 4).

In 1990, higher age-standardized rates of deaths DALYs and YLLs were found in men, and there were considerable differences in men and women. However, the differences in cancer deaths, DALYs, and YLLs between men and women decreased over the 1990–2019 period due to a significant reduction among men and a more moderate reduction among women. Moreover, women's age-standardized DALYs rate outpaced those of men in 2019. The

age-standardized YLDs rate decreased in mem from 0.56 (95% UI: 0.32 to 0.89) to 0.46 (95% UI: 0.25 to 0.73), but it increased in women from 0.94 (95% UI: 0.39 to 1.56) to 1.07 (95% UI: 0.44 to 1.78), causing a wider gap in YLDs between the sexes (Fig. 5).

Cancer burden attributable to secondhand smoke by geographic region

Figure 6 shows the geographic distribution of the cancer burden attributable to secondhand smoke in 2019 for both sexes combined. In 2019, age-standardized mortality higher than 3.00 was seen in most parts of the Balkan Peninsula, located in southeast Europe, Greenland—a country of North America—and two other Asian counties—China and Lebanon. A wide range of countries in Africa and South America had less than 0.50 age-standardized mortalities (Fig. 6A). The geographical disparities in the age-standardized DALY rate were similar to those in mortality: the highest rate was found in European countries, followed by North America (Fig. 6B). Among the top ten countries that had higher mortality rates, nine also had higher DALYs rates: Montenegro (Europe), Greenland (North America), Palau (Oceania), Hungary (Europe), North Macedonia (Europe), Serbia (Europe), Bosnia and Herzegovina (Europe), Solomon Island (Oceania), and Lebanon (Asia). Geographical distribution of YLDs and YLLs were not different from deaths and DALYs, suggesting that the majority of the top countries with highest rates were also from Europe (Fig. 6C, Fig. 6D). The lowest cancer burden was mainly seen in Africa in terms of deaths, DALYs, YLDs and YLLs.

Figure 7 shows the annual rate change in the cancer burden attributable to secondhand smoke from 1990 to 2019 for both sexes combined. In general, the average annual age-standardized cancer mortality decreased during the three decades in many regions, especially in North America and Oceania, with a reduction of more than 2.5% per year. Nevertheless, a wide range of countries in Africa, Asia and Europe (mostly in the Balkan Peninsula) experienced increased annual changes in age-standardized mortality (Fig. 7A). The change pattern for the average annual age-standardized DALYs rate remained the same as the pattern for mortality (Fig. 7B).

In terms of YLDs, the average annual rate decreased mainly in North America and Oceania. In contrast, nearly all locations in Africa experienced increased annual change in the age-standardized rate of YLDs, as did many countries in Asia, where the highest increase in annual rate change was found (Lebanon, 2.93%; followed by Saudi Arabia, 2.33%) (Fig. 7C). Similar to the change pattern for cancer mortality and DALYs, reductions in annual age-standardized YLLs rate were observed mainly in North America and Oceania, while increases were observed in Africa, Asia and Europe (mostly in the Balkan Peninsula) between 1990 and 2019 (Fig. 7D).

Cancer burden attributable to secondhand smoke by SDI

In 2019, all the rates were lower than the global level in high SDI countries except YLDs (0.84 vs. 0.77). In contrast, high-middle SDI countries and middle SDI countries had higher age-standardized rates of cancer deaths, DALYs, YLDs and YLLs than the global level. Low-SDI countries had the lowest age-standardized mortality (0.50, 95% UI: 0.30 to 0.74), DALYs rate (13.49, 95% UI: 7.69 to 20.17), YLDs rate (0.23, 95% UI: 0.10 to 0.38) and YLLs rate (13.27, 95% UI: 7.58 to 19.81) in 2019 (Table 4).

Table 4
Cancer burden attributable to secondhand smoke in 5 SDI groups for both sexes combined in 1990 and 2019 and percentage change from 1990 to 2019

	Age-standardized rate		Percentage change 1990–2019 (%)	*P*
	1990	2019		
Deaths				< 0.001
Global	1.84 (1.21, 2.63)	1.60 (1.01, 2.32)	-13.38 (-22.26, -4.32)	
High SDI	2.29 (1.48, 3.29)	1.22 (0.76, 1.79)	-46.83 (-49.97, -43.96)	
High-middle SDI	2.40 (1.57, 3.43)	2.13 (1.36, 3.02)	-11.25 (-21.91, -0.09)	
Middle SDI	1.75 (1.13, 2.53)	2.02 (1.27, 2.96)	15.90 (-2.28, 36.75)	
Low-middle SDI	0.88 (0.55, 1.27)	0.95 (0.60, 1.39)	8.87 (-6.56, 24.23)	
Low SDI	0.46 (0.27, 0.68)	0.50 (0.30, 0.74)	9.66 (-5.59, 25.87)	
DALYs				< 0.001
Global	48.49 (32.24, 69.09)	38.54 (24.77, 55.49)	-20.51 (-28.51, -12.23)	
High SDI	62.32 (40.76, 88.89)	30.52 (19.48, 43. 84)	-51.02 (-53.70, -48.49)	
High-middle SDI	64.02 (42.49, 91.23)	51.28 (33.07, 74.06)	-19.90 (-29.23, -9.69)	
Middle SDI	44.89 (28.79, 64.61)	46.97 (30.04, 68.18)	4.65 (-11.37, 23.39)	
Low-middle SDI	23.14 (14.59, 33.48)	24.45 (15.47, 35.31)	5.67 (-9.50, 20.36)	
Low SDI	12.22 (6.69, 18.22)	13.49 (7.69, 20.17)	10.43 (-5.43, 26.61)	
YLDs				< 0.001
Global	0.75 (0.42, 1.16)	0.77 (0.41, 1.20)	3.03 (-7.89, 13.87)	
High SDI	1.17 (0.64, 1.83)	0.84 (0.42, 1.34)	-28.01 (-36.74, -20.33)	
High-middle SDI	0.93 (0.52, 1.44)	1.03 (0.56, 1.6)	11.15 (-1.98, 25.13)	
Middle SDI	0.58 (0.32, 0.91)	0.84 (0.46, 1.31)	45.17 (22.84, 68.69)	
Low-middle SDI	0.32 (0.16, 0.51)	0.42 (0.20, 0.68)	31.96 (11.09, 50.02)	

Note: 1. Data in parentheses are 95% uncertainty intervals. 2. Age-standardized rates (per 100,000 people) based on GBD reference population.

	Age-standardized rate		Percentage change 1990–2019 (%)	*P*
	1990	2019		
Low SDI	0.18 (0.08, 0.29)	0.23 (0.10, 0.38)	28.99 (7.92, 50.32)	
YLLs				< 0.001
Global	47.74 (31.79, 68.14)	37.77 (24.12, 54.49)	-20.88 (-28.92, -12.41)	
High SDI	61.15 (39.98, 87.11)	29.68 (18.89, 42.86)	-51.46 (-54.05, -49.04)	
High-middle SDI	63.09 (41.66, 89.96)	50.25 (32.36, 72.78)	-20.35 (-29.79, -10.18)	
Middle SDI	44.31 (28.36, 63.80)	46.13 (29.41, 67.14)	4.12 (-12.00, 23.13)	
Low-middle SDI	22.82 (14.4, 33.01)	24.02 (15.10, 34.69)	5.30 (-9.71, 20.09)	
Low SDI	12.04 (6.88, 17.96)	13.27 (7.58, 19.81)	10.16 (-5.95, 26.40)	

Note: 1. Data in parentheses are 95% uncertainty intervals. 2. Age-standardized rates (per 100,000 people) based on GBD reference population.

As shown in Table 4, slight changes occurred in the disparities in cancer burden attributable to secondhand smoke among the five SDI groups within the thirty years. In 1990, the cancer burden was larger than the global level in countries with high SDI and high-middle SDI in terms of cancer deaths, DALYs, YLDs and YLLs. However, the largest decline in cancer burden caused by secondhand smoke was seen in High SDI countries between 1990 and 2019, resulting in a lower cancer burden than global level except for YLDs. Although reductions in all age-standardized rates also occurred in high-middle SDI countries, the rates of deaths, DALYs, YLDs and YLLs were still higher than the global level. For countries with middle or lower SDI, the cancer burden due to secondhand smoke in 2019 increased compared to that in 1990, yet the growth was only statistically significant in YLDs, which increased by 45.17% (95% UI: 22.84 to 68.69, $p < 0.001$), 31.96% (95% UI: 11.09 to 50.02, $p < 0.001$), and 28.99% (95% UI: 7.92 to 50.32, $p < 0.001$) in countries with middle SDI, low-middle SDI and low SDI, respectively (Table 5).

Figure 8 provides the trends in cancer burden attributable to secondhand smoke in different SDI groups from 1990 to 2019. Within that timeframe, the cancer burden substantially decreased in high-SDI countries. Age-standardized rates of deaths, DALYs, YLDs and YLLs remained modest climbing in high-middle SDI countries and were consecutively higher than the global level. The age-standardized mortality, DALYs rate, and YLLs rate in middle-SDI countries surpassed the global level from 1997, while YLDs rate exceeded from 2010 (Fig. 8).

Discussion

Principal Findings

To our knowledge, this is the first study that estimated the global cancer burden attributable to secondhand smoke. Our study found that age-standardized rates of cancer deaths, DALYs, and YLLs decreased significantly over the past three decades, but the absolute numbers are consecutively increasing, and the cancer burden due to secondhand smoke share in the total cancer burden has tended to increase in recent years. In terms of the distribution of cancer burden by demographics, older individuals and women incur a greater cancer burden attributable to secondhand smoke. From the regional level, it is revealed that there is a significant difference in the status quo and trend of attributable cancer burden across regions. In 2019, the concentration of cancer burden was seen in European countries, followed by North America and Oceania. Nevertheless, the latter two regions experienced decreases in cancer burden from 1990 to 2019. In contrast, Africa and Asia, which had lower cancer burdens in 2019, experienced increases in the annual rate changes in deaths, DALYs, YLDs and YLLs. For cancer burden by SDI, high-middle SDI countries and middle SDI countries had higher age-standardized rates of deaths, DALYs, YLDs and YLLs than the global level in 2019. Reduction in cancer burden caused by secondhand smoke is more encouraging in higher SDI countries. These findings pose implications to improve population health and reduce avoidable health loss.

Cancer burden attributable to secondhand smoke at the global level

According to the results, secondhand smoke climbed up to the tenth leading risk of cancer DALYs, resulting in increases in the absolute numbers of cancer deaths, DALYs, YLDs and YLLs, particularly in YLDs number, which doubled by 2019, and the rising annual proportion of cancer burden due to secondhand smoke in recent years. Additionally, there were reductions of 13%, 20% and 21% in the rates of deaths, DALYs and YLLs, respectively. These results are in consistence with the findings of a previous study that investigated cancer burden for all risk factors combined over thirty years.[18] This seeming paradox could, to some extent, be explained by the growth of the population and aging. A world population project led by the UN showed that the global population has been growing by over 1.0% per year, and life expectancy has been increasing from 64.5 in 1990 to 72.4 in 2019 globally.[20] As a result, there is a change in age structure that gives rise to a larger size and proportion of the older all over the world.[21] Cancer prevalence is much higher in older people than the young; for example, approximately half of the total cancer cases are aged 70 years or older in America.[22] Therefore, there is an increase in the number of cancer deaths but a decline in cancer mortality.

Furthermore, improvements in access to medical services might lead to an increase in prevalence and disability in cancer survivors who were exposed to secondhand smoke. Thanks to advances in cancer detection and treatments, many patients can be diagnosed at an early stage and receive life-sustaining therapy.[23] This is also the reason why there was a dramatic increase in cancer-related YLDs number. A previous study documented that the 5-year survival rate for patients with cancer improved for different types of cancer from 1990 to 2009,[22] implying that life years of the cancer patients lives with disability increased as well. Given the increases in absolute numbers and annual contribution of cancer burden attributable to secondhand smoke, there are challenges for health care systems that have not been well prepared for population growth and aging.[24] It is highly recommended to optimize medical services, such as promoting cancer screening for those at high risk and improving follow-up care for older individuals. In addition, infrastructure should be developed that can meet the needs of growing cancer survivors.

Cancer burden attributable to secondhand smoke by age and sex

In terms of the distribution of attributable cancer burden by demographic characteristics, older individuals incurred a greater burden in 2019. More than half of the cancer burden was concentrated in adults aged 55–75 for men and in adults aged 50–70 for women. The age-standardized rates of deaths, DALYs, YLDs and YLLs rose with age for both sexes. As mentioned above, a greater cancer burden in older individuals could be traced to population growth and aging. Additionally, older people are vulnerable to secondhand smoke exposure and have a cumulative risk of exposure to secondhand smoke, so they are more affected by tobacco once they have cancer. In addition, older people commonly have other morbidities that exacerbate cancer prognosis.[25] According to a report by the United States Centers for Disease Control and Prevention (CDC), approximately 80% of adults aged 65 years and older have at least one chronic condition, and 50% have at least two chronic conditions.[26] Chronic conditions could deteriorate the health loss caused by cancer.

Although there were declines in cancer mortality, DALYs rate, YLDs rate, and YLLs rate among other age groups in 2019 compared to those in 1990, older individuals experienced increases in cancer burden. Similarly, a study that investigated disease burden for all diseases combined revealed that age-standardized all-cause YLD rates are higher in older ages.[9] As discussed, the proportion of older individuals was higher in 2019 than in 1990 because of the growth of aging.[21] The advances in cancer detection and treatments and improvements in access to medical services might have led to the increase in prevalence and disability in cancer survivors who were exposed to secondhand smoke. In addition, it is more likely for them to develop other NCDs disease due to changes in lifestyle behaviors, such as poor physical activity, which also increase cancer risk and trigger more disease burden.[23] Once cancer occurs in the older, they may be more fragile, and their health might deteriorate rapidly.[25] Increasing burden in the older has important implications for health policy, including protecting the older from carcinogenic risks, ensuring earlier cancer screening, and providing long-term supportive care for older patients with cancer.[25]

In terms of sex differences, the gap in cancer burden attributable to secondhand smoke consecutively narrowed, resulting from a substantial decline among men and a slight increase among women. Notably, the age-standardized YLDs rate continued to rise among women, which was contrary to men. This pattern reflects that the efforts on smoking restrictions and cancer control do not equally bring the same benefits to men and women, although women are more likely to secondhand smoke and have an approximately 30% higher risk of cancer owing to secondhand smoke.[5] To some extent, this implies that the effect of health policies on women is not as favorable as on men, potentially reflecting inequalities in cancer prevention, intervention and treatment across genders over the past thirty years.[9] The underlying reasons for this inequality might be complex. Further studies are needed to explore the sex-specific distribution of attributable cancer burden and the disparity of cancer-related health policies in men and women.

Notably, women under 75 years had a significantly higher YLDs rate than men of the same age group in 2019, suggesting that health loss due to cancer is more common in women. One explanation for this is that women might be more attentive to disorders so that they actively seek treatment. In this sense, life time with cancer disability might be longer for women. Gender differences in cancer-related health loss should be further examined in future studies.

Cancer burden attributable to secondhand smoke by geographic region

In regard to the distribution of cancer burden across different regions, the concentration of cancer burden attributable to secondhand smoke was in Europe in 2019, particularly in countries from the Balkan Peninsula. Furthermore, the Balkan Peninsula also had a greater annual rate change in terms of cancer deaths, DALYs, YLDs and YLLs. This finding is consistent with previous studies.[18,23] It is probably driven by high tobacco prevalence, high cancer incidence and rapid aging. According to a WHO report, the prevalence rate of current tobacco use in Europe is nearly as high as the global level and just second to the South-East Asian in 2019; a relatively slower prevalence rate of decline was seen in the European region from 2000 to 2019.[27] More than 20% all-cause DALYs were attributable to tobacco use in the countries of Balkan Peninsula in 2019; more than 10% DALYs were attributable to tobacco use in the majority of other European countries.[18] On the other hand, Europe has higher cancer incidence for both sexes combined, and cancers that are related to much greater disease burden are more common in Europe.[23] For example, the incidence rate and mortality of breast cancer in Europe are relatively higher than those in other regions, while women are the main vulnerable population to breast cancer as well as secondhand smoke. Additionally, the UN project revealed that the European population is growing at a slow rate of 0.3%, but aging is rather rapid in most European countries,[20] in which the proportion of adults aged over 65 years will reach 24.3% by 2030.[26] This might also be a reason for the increase in the annual rate change of the attributable cancer burden.

Different from Europe, some countries in North America and Oceania had higher rates of cancer deaths, DALYs, YLDs and YLLs in 2019, yet the annual rate change of cancer burden decreased mainly in these two regions. The greater cancer burden due to secondhand smoke in 2019 might be explained by relatively high tobacco use and cancer incidence. The tobacco prevalence in North America and Oceania was lower than that in Europe in 2019, resulting in only 6%-8% of all-cause DALYs being attributable to tobacco use in both regions, but it is still higher than that in other regions.[18,27] Cancer incidence was also high in North America and Oceania;[23] for example, the breast cancer incidence rate is 91.6 per 100,000 in North America and 85.8 per 100,000 in Oceania. On the other hand, consistent with the global trends in population growth, the aging population is increasing in these regions as well.[20] As a result, the attributable cancer burden in North America and Oceania is not as high as that in Europe but is still higher than that in the other regions. The reduction in the annual change in cancer burden in North America and Oceania may be associated with a decline in smoking prevalence and optimization of cancer care. In Western countries, such as in the United States, cancer mortality is decreasing, particularly for cancer highly associated with tobacco use, since the tobacco epidemic started the earliest and peaked around the middle of the last century.[28–30] In addition, there have been considerable achievements in cancer treatment since the last century, especially in developed countries in the West, which have improved the clinical outcomes of cancer patients and prolonged their lifetimes. For instance, in the US, the total 5-year survival rate of breast cancer increased by more than 15% from 1975 to 2009; the overall 5-year survival rate of prostate cancer increased by more than 30% from 1975 to 2009.[22] Therefore, the secondhand smoke-related cancer burden tends to decrease annually.

Notably, Africa had lower rates of cancer deaths, DALYs, YLDs and YLLs than other regions in 2019, yet there was an increase in annual rate change in most African countries. An explanation for this pattern lies in the lower degree of cancer burden attributable to secondhand smoke at baseline in Africa. Thus, although the cancer

burden is rising annually in Africa, it still had a lower cancer burden than other regions in 2019. Furthermore, tobacco prevalence is consecutively lower in Africa than in other regions over the past years.[27] Nevertheless, due to the increasing growth in population, which doubled from 1990 to 2019 with an average annual rate of over 2.4%,[19] African countries experienced an increase in the annual change of cancer due to secondhand smoke. Moreover, poor medical treatment and limited access to well-integrated survivorship care are also triggers of rising trends of cancer burden in Africa.[31] To avoid continuing growth in cancer burden attributable to secondhand smoke, it calls for urgent action to improve health for he older and promote medical services for cancer patients.[22,25]

A rising annual rate change in cancer burden was also seen in many Asian countries, among which China stood out and had a relatively greater cancer burden attributable to secondhand smoke than other Asian countries in 2019. This finding might stem from several aspects. First, all DALYs caused by smoking in Asia are relatively high. According to GBD Study 2019, in many parts of Asia, tobacco exposure was attributed to 10–20% of DALYs for all causes combined, while in two provinces of China—Liaoning and Heilongjiang—attributable DALYs accounted for more than 20%, which was much higher than other locations.[18] Second, during the past years, there was a large reduction in tobacco prevalence, which fell by more than 10%, yet the average prevalence (25%) was still much higher in the Asian region.[30] In particular, the overall smoking rate among adults aged 15 years and older was 26.6% in China in 2018, 50.5% for men and 2.1% for women. More than 40% of the adults reported being exposed to secondhand smoke either at home or in other public places. [32] Third, Asia is the most populous region, accounting for a considerable percentage of the aging population worldwide.[20] It was projected that adults aged over 65 years will be up to 12% in Asia by 2030. China, as the most populous country, is experiencing a decline in fertility and an increase in the average life span, resulting in an acceleration in the change in age structure.[21] Last, limited medical resources and less mature cancer treatment potentially lead to unsatisfactory clinical outcomes.[33] Regardless of medical resource distribution or advanced therapy for cancer patients, there are differences among China and other countries. In sum, health loss due to secondhand smoke is increasing annually in Asia, posing remarkable challenges to individuals' health and health systems. In this sense, it is recommended to reverse the trends through sustained efforts, such as high taxation, smoking advertisement bans, and improvement in cancer screening and treatment.[9,18]

Cancer burden attributable to secondhand smoke by SDI

It was found that there were wide disparities in cancer burden attributable to secondhand smoke among the five SDI groups. Although age-standardized rates of cancer deaths, DALYs, YLDs and YLLs were higher in high SDI and high-middle SDI countries in 1990, they decreased significantly in high SDI countries, while they decreased slightly in high-middle SDI countries, resulting in a higher cancer burden attributable to secondhand smoke in high-middle SDI than the global level. In contrast, the cancer burden attributable to secondhand smoke increased slightly in other SDI countries, especially in middle-SDI countries, which surpassed the global level in later years. That is, the cancer burden decreases more significantly as the SDI level increases, which has also been discovered by previous studies.[9,18,23] The drivers behind this finding could be complicated, as SDI is a compositive index.

Smoking is not largely correlated with SDI,[18] which indicates that the imbalance in cancer burden is primarily stemmed from socioeconomic development and cancer control across countries. Approximately 50% of cancer cases are seen in high SDI countries, but only 30% of cancer deaths, 25% of cancer DALYs, and 23% of cancer YLLs occur in high SDI countries.[9] A higher SDI generally reflects desirable social and economic status, which

enables cancer patients to receive advanced treatment and incur less health loss.[18] However, the greatest increase (52%) in cancer incidence was seen in middle SDI countries from 2007 to 2017.[9] The cancer burden will shift to less developed countries due to population growth and aging and the increasing prevalence of risk factors.[34]

These findings imply an insufficiency in cancer prevention and treatment across less developed regions, which demands interventions to address health inequality worldwide.[22] To address this international variation, recognizing the interdependencies between socioeconomic status and health is the first step.[9] Lower SDI countries should make more efforts to promote smoking cessation and cancer prevention and control, such as raising tobacco tax, banning smoking in public places, forbidding tobacco advertisement, providing early cancer screening for those at high risk, and improving treatment and follow-up care for cancer patients.[23] In addition, economic support should be provided to the patients for whom cancer treatment expenditures, including costs for both short-term and long-term care, might be catastrophic.

Limitations

Two limitations of this study should be noted. First, the global burden of cancer burden attributable to secondhand smoke might be underestimated because data used in this study were directly extracted from the GHDx database, and data for some locations, such as Western Sahara (Africa), French Guiana (South America) and Svalbard (Europe), are not available. Although this study analyzed the data related to cancer burden attributable to secondhand smoke in most countries or regions of the world, it is warranted to collect more comprehensive data and conduct further analysis on the cancer burden attributable to secondhand smoke. Second, the disease burden of different types of cancer attributable to secondhand smoke was not assessed in this study. Data on all cancers associated with secondhand smoke are available in the database, whereas the data are not classified according to cancer types. Given the close association between different types of cancer and secondhand smoke, future studies are needed to explore disease burden due to secondhand smoke by cancer type in future studies.

Conclusion

Although the rates of cancer mortality, DALYs, and YLLs due to secondhand smoke have decreased globally in the past three decades, the contribution of cancer burden attributable to secondhand smoke showed increasing trends since 2004, as did the life years that cancer patients live with disability or lose. More attention should be given to older individuals and women among whom the cancer burden caused by secondhand smoke exposure has increased or decreased slightly. It is advisable to take more effective actions to enforce a ban on smoking to slow the growth of cancer burden, especially for Asian and African countries with a middle SDI or lower level. Further studies are needed to investigate the causes of disparities and trends in cancer burden attributable to secondhand smoke worldwide and to improve our understanding of the contribution of secondhand smoke to the burden of different types of cancer.

Abbreviations

CDC: Centers for Disease Control and Prevention, The United States of America

DALYs: disability-adjusted life-years

GBD: Global Burden of Disease

GHDx: Global Health Data Exchange

HPV: human papillomavirus

IARC: International Agency for Research on Cancer

ICD-10: International Statistical Classification of Disease and Related Health Problem, Tenth Revision

IHME: Institute for Health Metrics and Evaluation

NCDs: non-communicable diseases

NCI: National Cancer Institute of America

SDI: Socio-Demographic Index

WHA: World Health Assembly

WHO: World Health Organization

YLDs: years lived with disability

YLLs: years of life lost

UI: uncertainty interval

UN: United Nations

US: the United States of America

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the Global Health Data Exchange website (http://ghdx.healthdata.org).

Competing interests

The authors declare that they have no competing interests.

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Authors' contribution

All authors developed the study concept and design. MM contributed to the statistical analysis, data interpretation and manuscript writing. YL and YJ provided overall guidance and critical revision. JW and MW provided technical support for cancer-related study progress and critical comments. All authors revised the manuscript and approved the final version.

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Figures

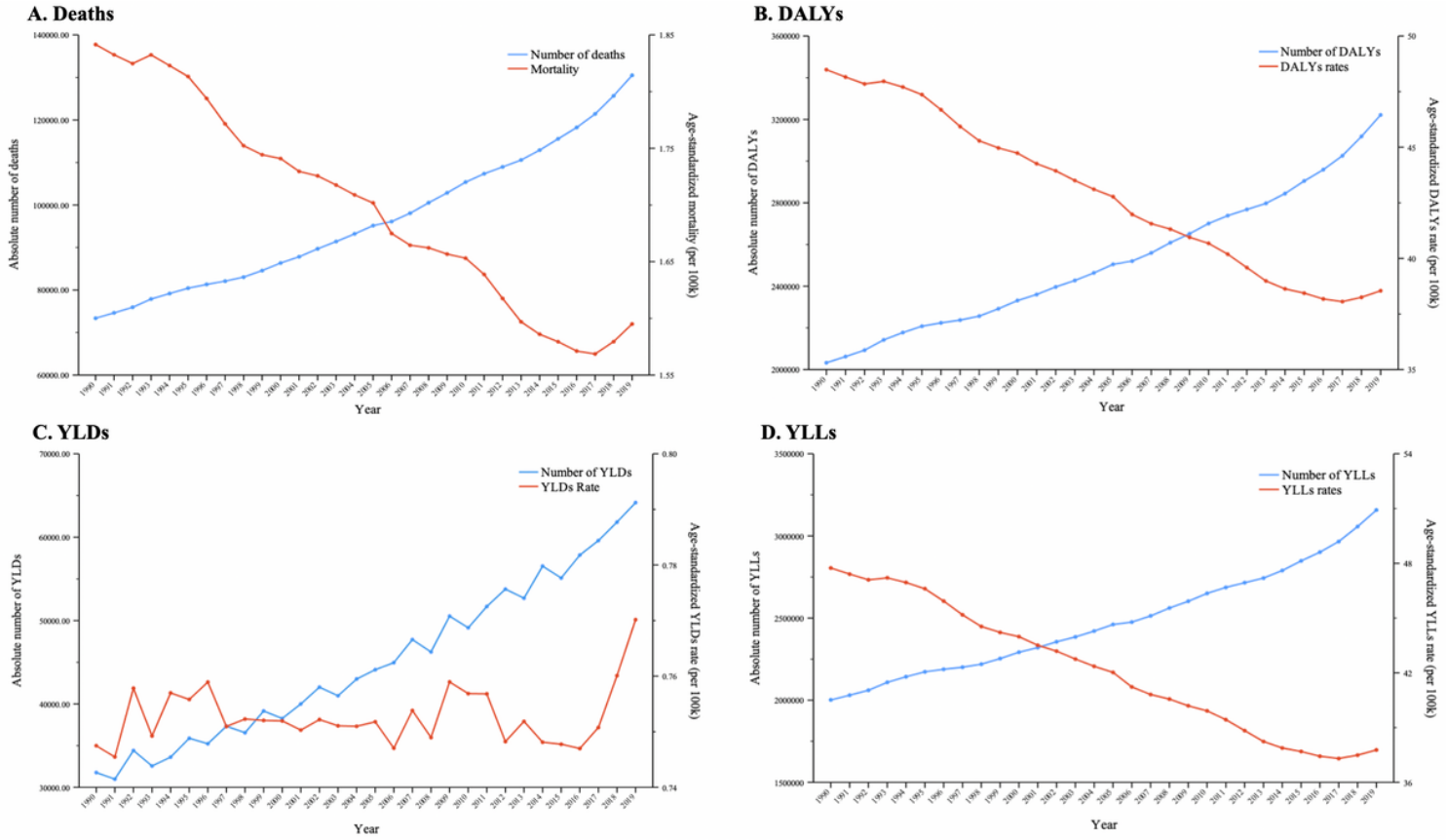

Figure 1

Trends in global cancer burden attributable to secondhand smoke for both sexes combined from 1990 to 2019. A. Deaths; B. DALYs; C. YLLs.

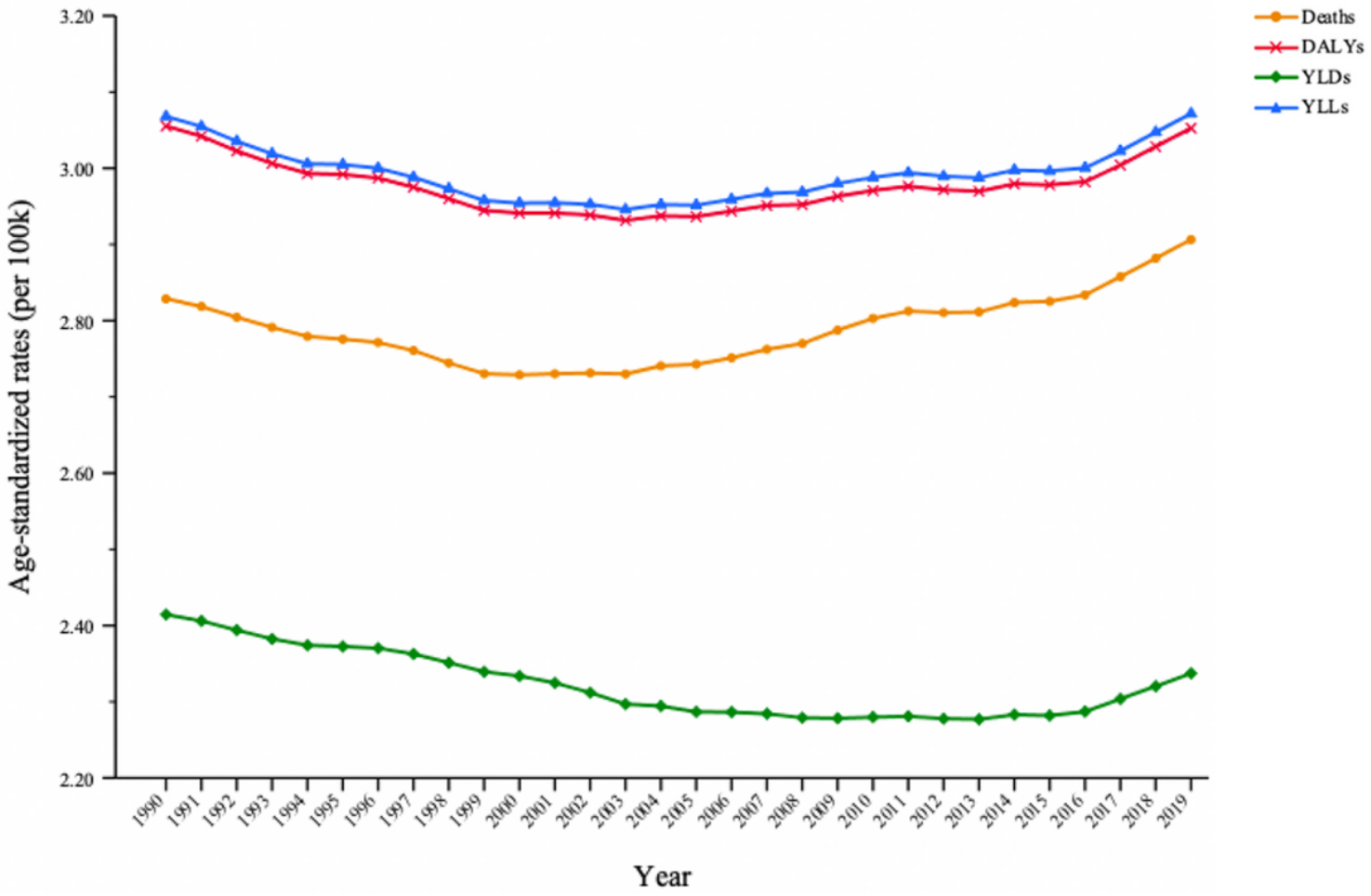

Figure 2

Trends in the proportion of cancer burden attributable to secondhand smoke in total cancer burden caused by all risk factors for both sexes between 1990 and 2019

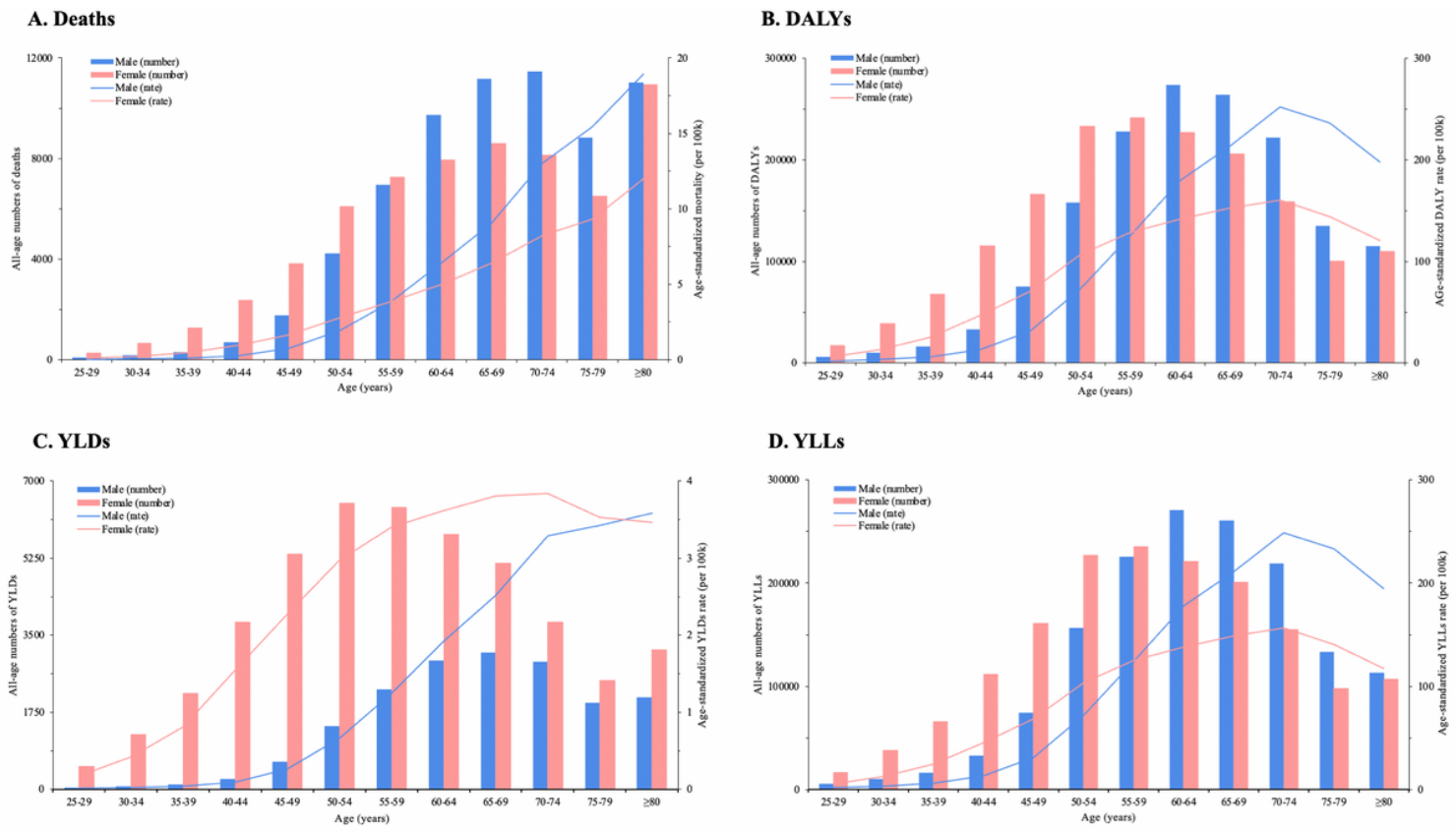

Figure 3

Age-specific global cancer burden attributable to secondhand smoke by sex in 2019. A. Deaths; B. DALY; C. YLDs; D. YLLs.

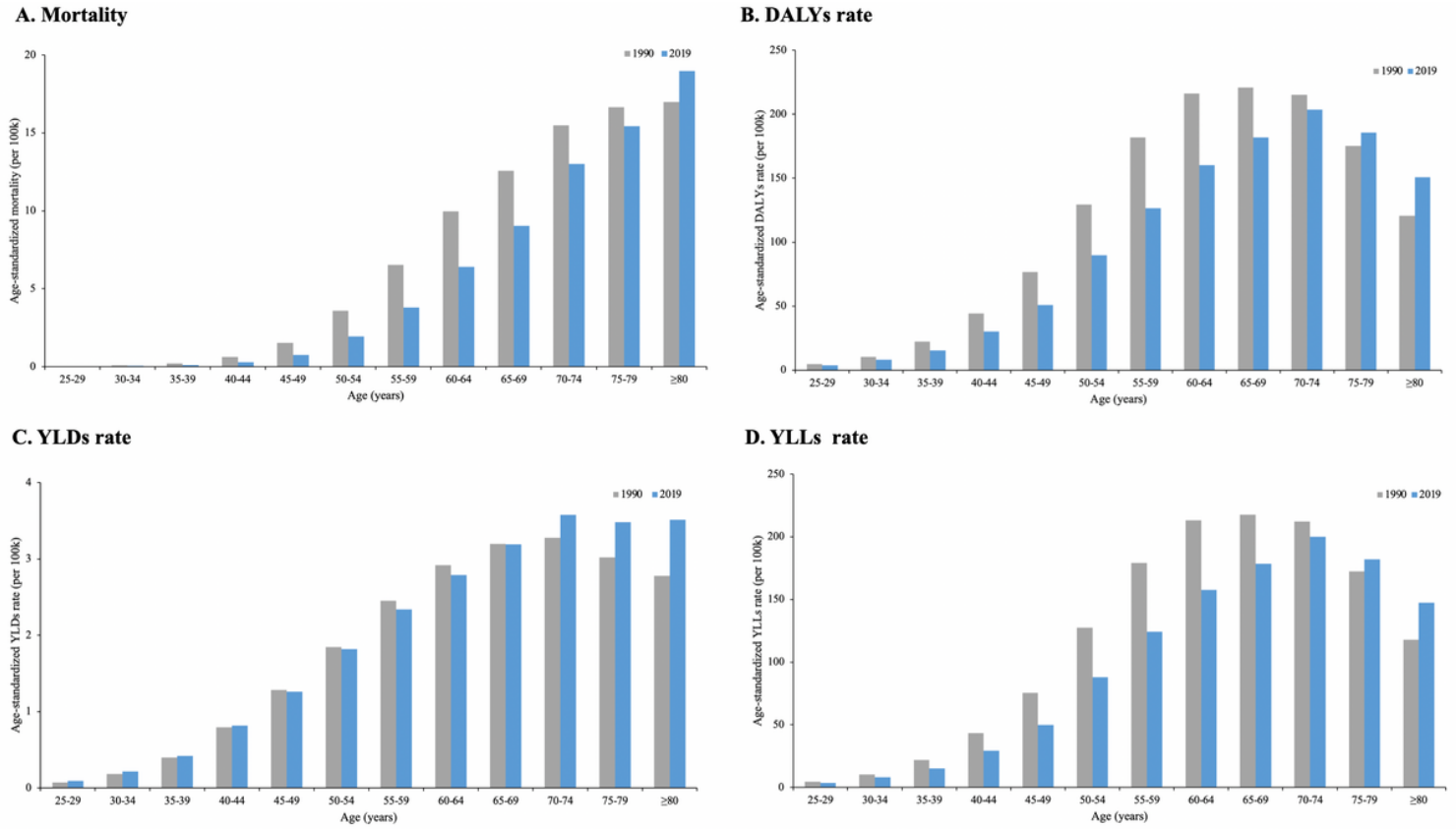

Figure 4

Global cancer burden attributable to secondhand smoke by age in 1990 and 2019. A. Mortality; B. DALY rate; C. YLD rate; D. YLL rate.

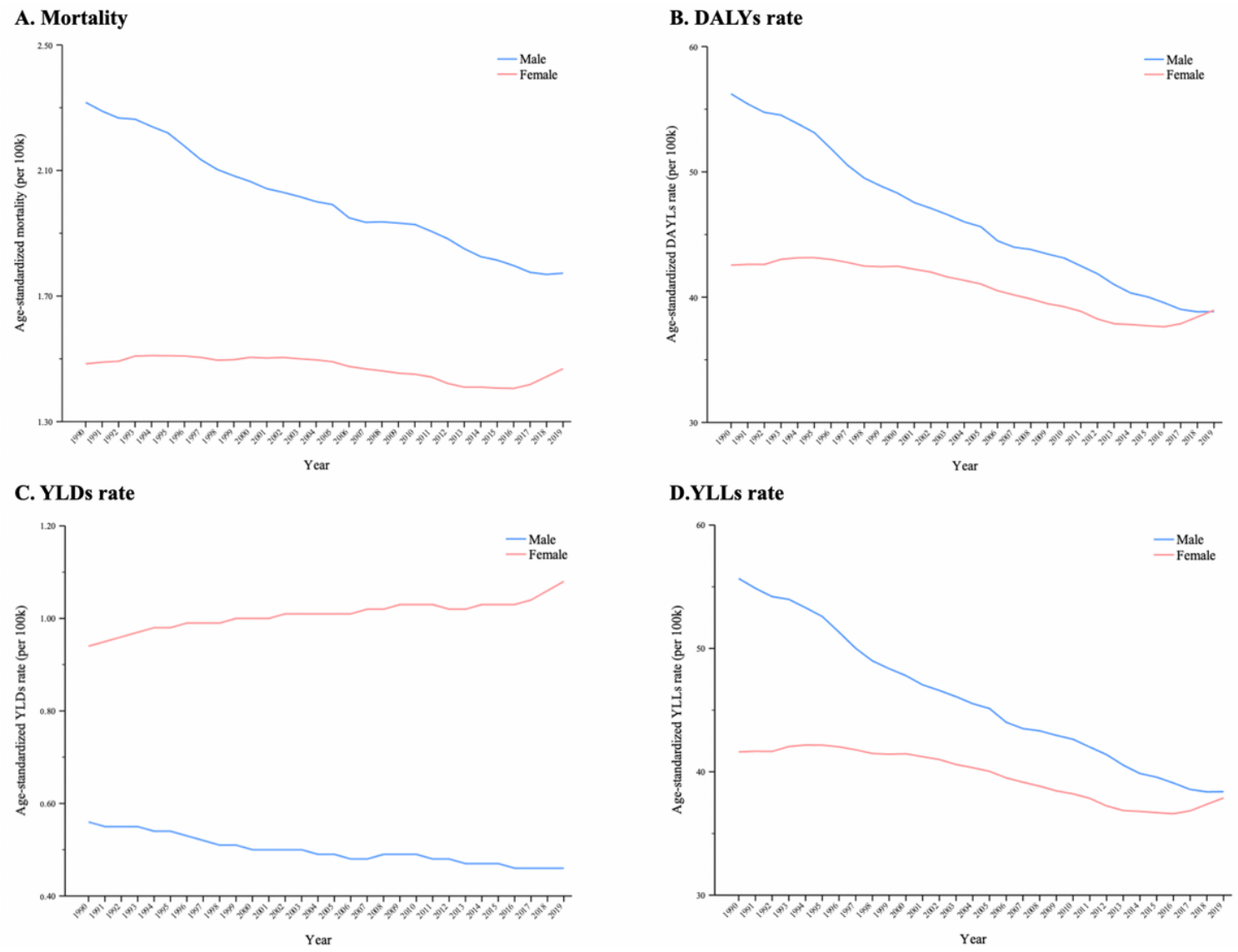

Figure 5

Trends in global cancer burden attributable to secondhand smoke by sex from 1990 to 2019. A. Mortality; B. DALY rate; C. YLDs rate; D. YLLs rate.

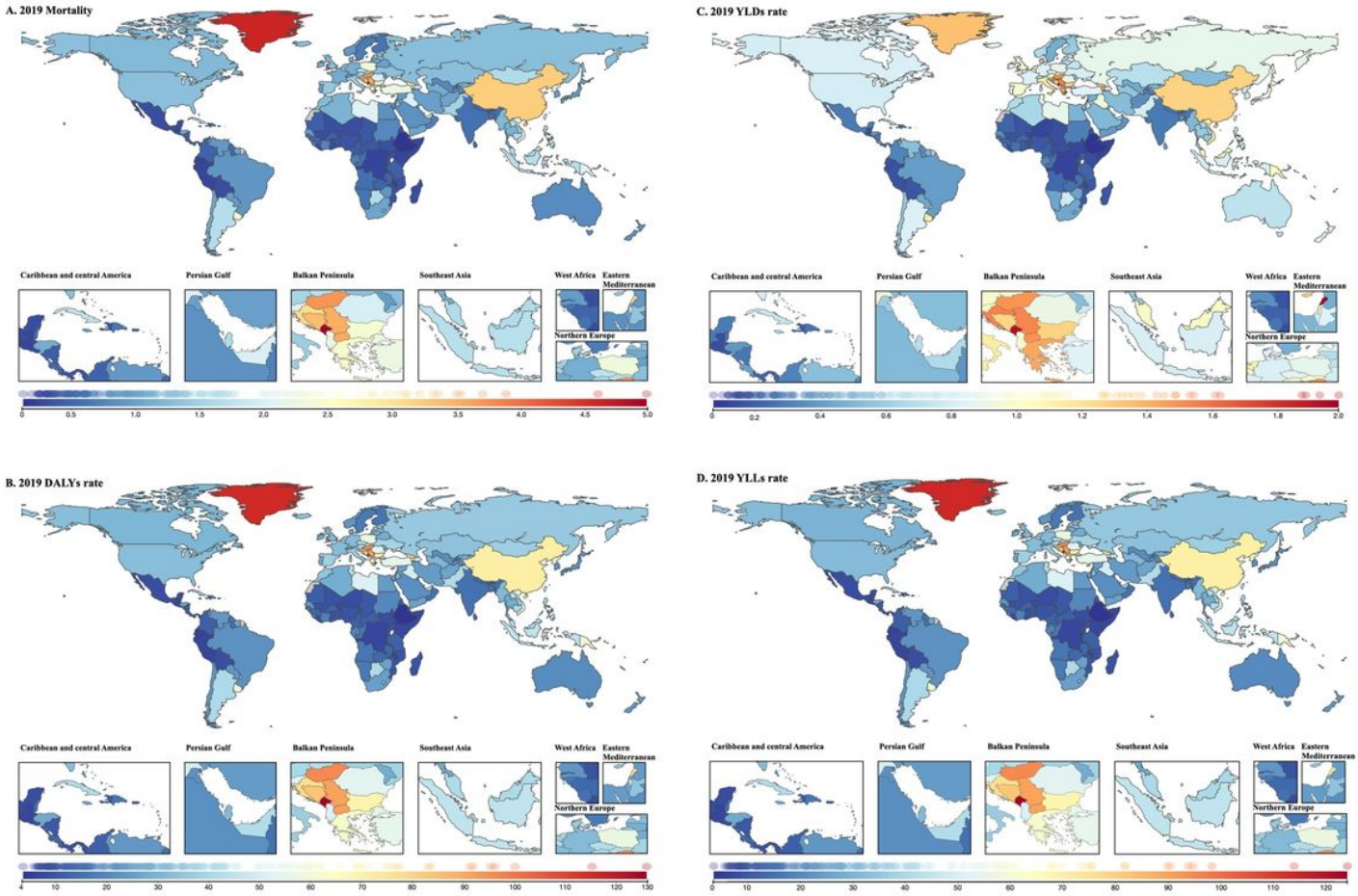

Figure 6

Geographical distribution of cancer burden attributable to secondhand smoke for both sexes combined in 2019. A. 2019 Mortality; B. 2019 DALYs rate; C. 2019 YLDs rate; D. 2019 YLLs rate.

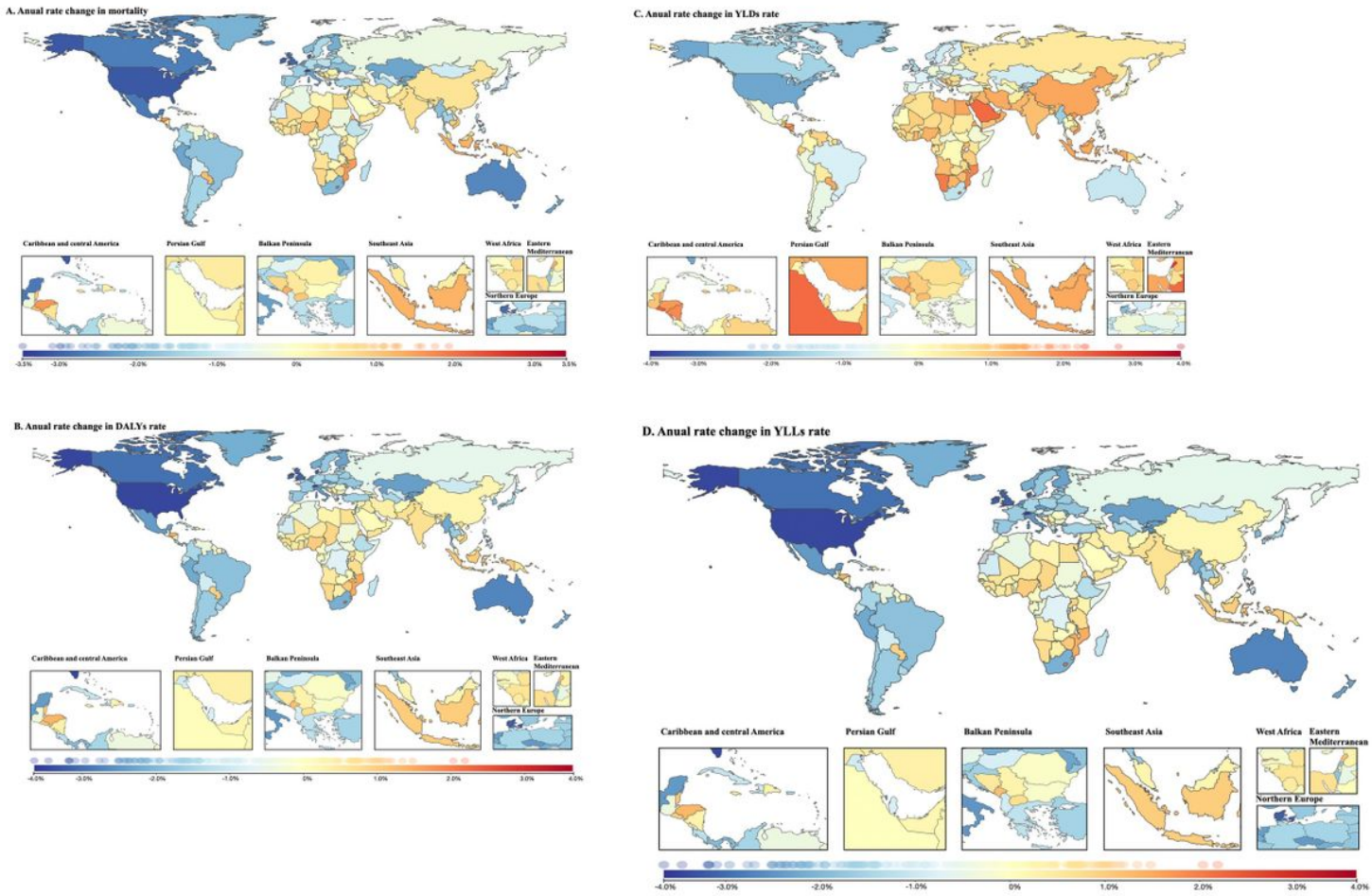

Figure 7

Annual rate change in cancer burden attributable to secondhand smoke for both sexes combined from 1990 to 2019. A. Annual rate change in mortality; B. Annual rate change in DALYs rate; C. Annual rate change in YLDs rate; D. Annual rate change in YLLs rate.

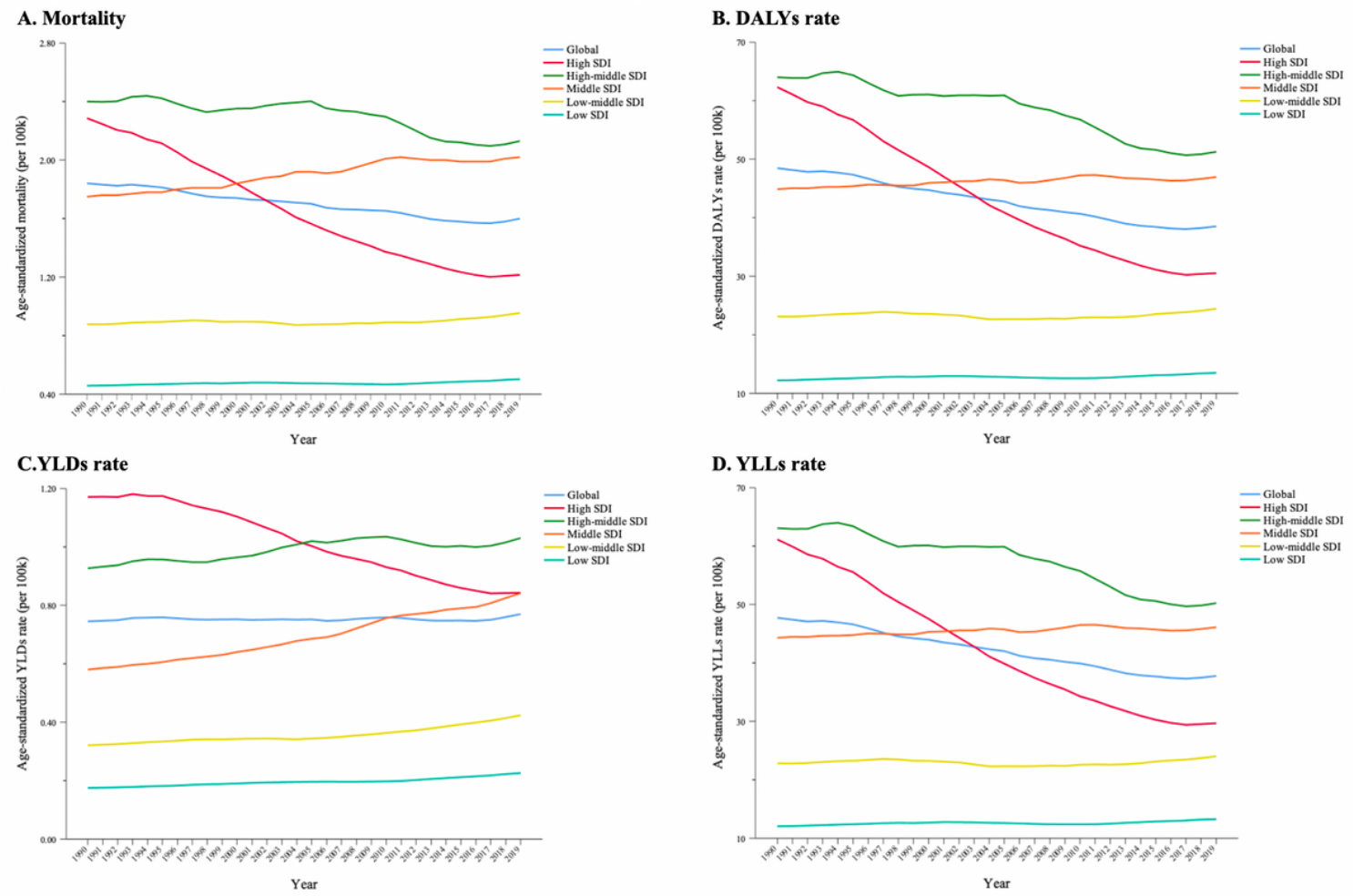

Figure 8

Trends in cancer burden attributable to secondhand smoke in 5 SDI groups for both sexes combined from 1990 to 2019. A. Deaths; B. DALYs rate; C. YLDs rate; D. YLLs rate.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix.docx