Original Article

Temporal trends of kidney cancer incidence and mortality from 1990 to 2016 and projections to 2030

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Background: This study aims to present the trends of incidence and mortality of kidney cancer from 1990 to 2016 by age, gender, geographical region, regional, and sociodemographic index (SDI), and then forecast the future trends to 2030.

Methods: Data of this study were gathered from the Global Burden of Disease Study (GBD), including 195 countries and territories, accounting for 21 regions. Over-time trends from 1990 to 2016 were analyzed by gender, geographical region, age range and SDI. Based on the big data, we forecasted the future trends to 2030 by ARIMA model. All the data were analyzed by R software (x64 version 3.5.1), SAS (version 9.3) and SPSS (version 22.0).

Results: Globally, in 2016, there were 342,100 [95% uncertainty interval (UI), 330,759–349,934] incident cases of kidney cancer and the number of deaths were 131,800 (127,335–136,185). The age-standardized incidence rate (ASIR) and death rate (ASDR) were 4.97 (4.81–5.09) per 100,000 and 2.00 (1.93–2.06) per 100,000, respectively. Globally, the estimated risk of kidney cancer for male within the age of 30 and 70 is around 0.79% compared to 0.41% for female. In other words, the probability of developing kidney cancer was generally higher in male than in female. By 2030, incidence of kidney cancer in both sexes are projected to increase substantially in high SDI, followed by middle SDI, low-middle SDI, and low SDI countries. High SDI and low SDI countries will also have increased mortality rates of kidney cancers. Globally, the trends in deaths due to kidney cancer will remain stable.

Conclusions: The incidence and death rate of kidney cancer are highly variable among SDI countries and regions but have increased uniformly from 1990 to 2016. By 2030, the future incidence of kidney cancer will grow continuously especially in high SDI countries, middle SDI, low-middle SDI, and low SDI countries.

Keywords: Kidney cancer; over-time trends; projections; incidence; mortality

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Introduction

Kidney cancer accounts for a large proportion of urologic caner and leads to large amount of people's death (1). In the context of a growing and aging global population, kidney cancer is considered to be growing both in incidence among older individuals and men (2). It has become a threat to the health of people in most countries. Worldwide, kidney cancer is the sixth most frequently diagnosed cancer in men and the tenth most common cancer in women, accounting for an estimated 73,820 new cases and 14,770 deaths in 2019 (3). It can be seen that the burden of disease caused by kidney cancer is very worthy of attention.

Due to the international variations in morbidity and mortality of urologic cancer, people are increasingly interested in the burden of urinary cancer (4-7). As growing demands for relative knowledge about kidney cancer, epidemiology researches are urgently needed as inference to make health decisions. However, prior studies lacked analysis of temporal trends in morbidity and mortality in kidney cancer, as well as analysis of morbidity and mortality by sex, age, SDI and region. Decision makers are supposed to provide effective policies on kidney cancer prevention, screening and treatment and sensible allocation of health care resources. But necessary data to develop health policies for kidney cancer worldwide, including epidemiology of kidney cancer and future trends of incidence and mortality rates, are not widely available.

Description of temporal trends in incidence and mortality of kidney cancer is essential for its future prevention and control. In this study, we aim to present these over-time trends from 1990 to 2016 by age, sex, region, and SDI, and then, based on the large amount data of kidney cancer incidence and deaths, we forecast the future trends of incidence and mortality worldwide to 2030. Finally, we point out countries and regions with high incidence of kidney cancer in the future and provide epidemiology reference for future prevention and control of kidney cancer. Paying attention to incidence characteristics of kidney cancer is essential for providing detailed information on kidney cancer prevention and screening.

Methods

We extracted the kidney cancer incidence and mortality data from the Global Burden of Disease Study (GBD) database (ghdx.healthdata.org). Detailed analytical methods for estimating the incidence, mortality, disability-adjusted life-years (DALYs) have been reported previously (8-13). The present study and detailed approach are in line with the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER) (14). Explanations of the estimation process and all materials as well as data involved in the methodology can be found in the numerous tables in the Supplementary materials (*Tables S1-S7* and tables online: http://cdn.amegroups.cn/static/application/bf0515116d9e2a9f90889619ab2e5cce/tau.2020.02.23-1.pdf; http://cdn.amegroups.cn/static/application/9f3529822bfb26286fdf162547922d15/tau.2020.02.23-2.pdf) (9,15-17). International Classification of Diseases 10 (ICD-10) codes mapped to the GBD cause list for kidney cancer incidence and mortality are C64-C64.2, C64.9-C65.9, Z80.51, Z85.52-Z85.54 and C64-C65.9, D30.0-D30.1, D41.0-D41.1, respectively. For the year 2016, we assessed national kidney cancer burden for 195 countries and territories. All rates are reported per 100,000 person-years. The age-standardized rates were calculated according to the GBD world population standard (1). Uncertainty intervals (UIs) were also reported for all estimates.

Data for the death rates of kidney cancer were obtained from vital registration systems and cancer registries. Cancer incidence data are used to simulate mortality in places where do not contain cancer mortality data by multiplying the incidence by mortality-to-incidence ratio which is separately modeled. These mortality estimates are classified as mortality data from the other sources and are used in a cause of death ensemble model (CODEm) (9,13). Cancer incidence rates were estimated by dividing the final cancer-specific mortality estimates by the mortality-to-incidence ratio. As in the GBD 2015, we estimated the impact of population ageing, population growth, and change in age-specific rates on the change of incident cases from 2006 to 2016 (8). Results were stratified by using sociodemographic index (SDI) countries.

SDI is a comprehensive indicator which includes fertility, education and income. It has been proved that SDI has a good correlation with health outcomes (Supplementary materials) (8). All the data was analyzed by R software (x64 version 3.5.1), SAS (version 9.3) and SPSS (version 22.0).

Results

Over-time trends of incident cases of kidney cancer from 1990 to 2016

Globally, kidney cancer incident cases increased by nearly 102% from 1990 (169,514; 95% UI, 166,246–173,338) to 2016 (342,100; 95% UI, 330,759–349,934). For SDI countries, in terms of absolute numbers, the highest kidney cancer incidence rates occurred in high SDI countries (160,805, 95% UI, 154,689–165,708), followed by high-middle SDI countries (81,637; 95% UI, 77,842–85,447), middle SDI countries (67,625; 95% UI, 65,243–69,419), low-middle SDI countries (25,876; 95% UI, 24,799–26,806), and low SDI countries (7,308; 95% UI, 6,413–8,127) in both sexes. Among regions, the three highest kidney cancer incident rates were observed in Eastern Europe (68,857; 95% UI, 64,818–72,034), high-income North America (63,291; 95% UI, 61,542–65,156), and East Asia (46,739; 95% UI, 43,375–48,820). In 2016, kidney cancer was more common in men, with 211,102 incident cases compared to women, with 130,997 cases (*Table 1*).

Over-time trends of deaths of kidney cancer from 1990 to 2016

Globally, there were 131,800 (95% UI, 127,335–136,185) deaths from kidney cancer in 2016, nearly 2.0-fold the number in 1990 (67,306; 95% UI, 65,806–68,836). Death rates changed by 3.63% from 1990 to 2016 at a global level. Among SDI countries, the highest burden of kidney cancer deaths occurred in high SDI countries (61,827; 95% UI, 59,214–63,852), followed by high-middle SDI countries (30,159; 95% UI, 27,501–33,257), middle SDI countries (26,309; 95% UI, 25,106–27,454), low-middle SDI countries (10,209; 95% UI, 9,667–10,688), and low SDI countries (3,246; 95% UI, 2,845–3,569) in both sexes. In terms of regions, Western Europe (30,035; 95% UI, 28,249–31,447) had the highest number of kidney cancer deaths in both sexes. High-income North America (18,446; 95% UI, 17,879-19,013) ranked second for kidney cancer deaths. East Asia (16,955; 95% UI, 15,938–17,772) experienced the third highest number of kidney cancer deaths in both sexes. In 2016, mortality of kidney cancer was much higher in men compared to women, with the death cases number of 86,051 and 45,749, respectively (*Table 1*).

Over-time trends of kidney cancer in age-standardized incidence rate (ASIR) from 1990 to 2016

Globally, ASIR changed by 10.94% from 1990 to 2016. High SDI countries had the highest ASIR in 2016, followed by high-middle SDI and middle SDI countries. The change pattern of ASIR between 1990 and 2016 reveals a significant increase of over 100% in East Asia (3.66; 95% UI, 3.31–3.82) in males and (2.92; 95% UI, 2.70–3.06) in both sexes. Concomitantly, some regions with high incidence rates such as Central Latin America (50.72% for both sexes, and 70.65% for males), tropical Latin America (59.11% for both sexes, 65.73% for males, and 50.41% for females), and North Africa and the Middle East (53.54% for males) experienced an increase of over 50% in ASIR. The highest male-to-female ratio for ASIR could be found in East Asia at 2.9 while Andean Latin America had the lowest male-to-female ratio at 0.9. Globally, the age-standard kidney cancer incidence rate (per 100,000 people) in 2016 among men [6.54 (6.28–6.73)] was 1.8 times higher than among women [3.62 (3.50–3.71)]. ASIRs for both sexes increased significantly from 1990 to 2016, with the greatest increases among men (*Table 2*, *Figures 1*,*2*).

Over-time trends of kidney cancer in age-standardized death rate (ASDR) from 1990 to 2016

Among SDI countries, the highest changes in ASDR between 1990 and 2016 increased in middle SDI countries (38.46% for both sexes, 58.93% for males). Regionally, the highest changes in ASDR between 1990 and 2016 increased in East Asia, followed by Eastern Europe, South Asia, and Southeast Asia. ASDR decreased significantly in regions with high kidney cancer burdens such as Southern Latin America and the Caribbean. On a global scale, the male-to-female ratios for ASIR and ASDR rates were 1.8 and 2.3, respectively. Globally, the age-standard kidney cancer death rate (per 100,000 people) among men [2.88 (2.77–2.99)] was approximately 2.3-fold as high as among women [1.27 (1.22–1.34)]. Deaths from kidney cancer increased in both sexes and different age groups, with an annual growth rate of 3.63%. However, ASDRs for females decreased 7.30% (*Table 2*, *Figures 2*,*3*).

Table 1 Global and regional kidney cancer incident and death cases by geography, gender and SDI, 1990 and 2016

Location	Incident cases, global and regional						Death cases, global and regional					
	1990			2016			1990			2016		
	Male	Female	Both	Male	Female	Both	Male	Female	Both	Male	Female	Both
Global	97,304 [93,751–101,153]	72,210 [70,539–74,905]	169,514 [166,246–173,338]	211,102 [202,968–217,539]	130,997 [126,867–134,227]	342,100 [330,759–349,934]	40,843 [39,257–42,283]	26,464 [25,929–27,186]	67,306 [65,806–68,836]	86,051 [82,478–89,444]	45,749 [43,905–48,047]	131,800 [127,335–136,185]
High SDI	55,601 [54,254–56,865]	36,783 [36,051–37,514]	92,384 [90,804–93,882]	100,993 [96,455–105,229]	59,812 [57,563–61,666]	160,805 [154,689–165,708]	22,913 [22,418–23,395]	13,971 [13,714–14,241]	36,884 [36,307–37,432]	40,088 [37,992–41,764]	21,739 [20,853–22,568]	61,827 [59,214–63,852]
High-middle SDI	23,363 [20,978–25,564]	18,090 [17,243–18,994]	41,453 [38,713–43,865]	49,957 [46,833–53,358]	31,680 [29,991–33,619]	81,637 [77,842–85,447]	9,218 [8,351–9,983]	6,062 [5,794–6,329]	15,280 [14,319–16,110]	19,720 [17,506–22,157]	10,439 [9,020–12,488]	30,159 [27,501–33,257]
Low SDI	1,712 [1,419–1,998]	1,508 [1,233–2,174]	3,220 [2,786–4,043]	4,017 [3,331–4,626]	3,291 [2,986–3,636]	7,308 [6,413–8,127]	807 [686–946]	615 [538–803]	1,422 [1,272–1,635]	1,974 [1,659–2,246]	1,272 [1,143–1,397]	3,246 [2,845–3,569]
Low-middle SDI	5,325 [4,769–6,114]	4,539 [4,120–5,624]	9,864 [9,306–10,736]	15,568 [14,659–16,426]	10,308 [9,972–10,682]	25,876 [24,799–26,806]	2,438 [2,020–2,866]	1,734 [1,529–2,039]	4,173 [3,685–4,597]	6,593 [6,149–7,019]	3,616 [3,396–3,843]	10,209 [9,667–10,688]
Middle SDI	11,918 [11,480–12,908]	11,547 [11,091–12,226]	23,466 [22,855–24,655]	41,399 [38,947–42,959]	26,226 [25,416–26,920]	67,625 [65,243–69,419]	5,456 [5,190–5,939]	4,065 [3,915–4,253]	9,522 [9,243–9,962]	17,646 [16,560–18,606]	8,664 [8,351–9,005]	26,309 [25,106–27,454]
High-income Asia Pacific	4,106 [3,997–4,346]	2,256 [2,198–2,319]	6,362 [6,237–6,622]	10,948 [9,833–11,615]	5,862 [5,419–6,169]	16,810 [15,358–17,662]	2,040 [1,978–2,128]	1,030 [998–1,064]	3,071 [2,999–3,170]	5,524 [4,875–6,104]	2,749 [2,516–2,989]	8,273 [7,474–8,924]
Western Europe	26,652 [25,663–27,669]	16,798 [16,209–17,395]	43,450 [42,323–44,595]	43,685 [40,611–46,310]	25,172 [23,650–26,463]	68,857 [64,818–72,034]	12,119 [11,777–12,502]	7,565 [7,350–7,786]	19,684 [19,264–20,109]	19,463 [18,154–20,625]	10,572 [9,991–11,210]	30,035 [28,429–31,447]
Andean Latin America	381 [347–424]	535 [481–617]	917 [846–1,013]	1,115 [1,012–1,217]	884 [823–952]	1,999 [1,867–2,118]	183 [165–203]	201 [182–229]	385 [357–418]	525 [432–627]	328 [278–387]	853 [749–963]
Central Latin America	1,719 [1,674–1,766]	1,889 [1,827–1,947]	3,608 [3,532–3,686]	6,189 [5,919–6,440]	4,819 [4,674–4,970]	11,008 [10,702–11,308]	820 [792–850]	720 [695–745]	1,540 [1,502–1,578]	2,559 [2,399–2,739]	1,567 [1,489–1,649]	4,125 [3,954–4,329]
Southern Latin America	2,205 [2,094–2,323]	2,945 [2,786–3,113]	5,150 [4,944–5,352]	4,789 [4,471–5,096]	2,760 [2,594–2,949]	7,549 [7,175–7,926]	1,076 [1,012–1,146]	1,260 [1,187–1,340]	2,335 [2,241–2,441]	2,199 [1,937–2,483]	1,107 [976–1,258]	3,306 [3,001–3,634]

Table 1 (*continued*)

Table 1 (*continued*)

Location	Incident cases, global and regional						Death cases, global and regional					
	1990			2016			1990			2016		
	Male	Female	Both	Male	Female	Both	Male	Female	Both	Male	Female	Both
Tropical Latin America	1,549 [1,486–1,611]	1,402 [1,340–1,469]	2,951 [2,864–3,054]	5,439 [5,207–5,654]	3,927 [3,798–4,055]	9,366 [9,115–9,613]	721 [684–754]	497 [477–519]	1,218 [1,177–1,261]	2,360 [2,221–2,507]	1,341 [1,270–1,418]	3,701 [3,539–3,862]
North Africa and Middle East	2,141 [1,861–2,440]	1,673 [1,464–2,253]	3,814 [3,475–4,444]	6,954 [6,250–7,621]	4,414 [4,006–4,714]	11,368 [10,692–12,159]	1,039 [895–1,246]	636 [573–792]	1,675 [1,500–1,862]	2,818 [2,477–3,179]	1,363 [1,214–1,513]	4,181 [3,807–4,597]
High-income North America	21,609 [20,718–22,391]	15,367 [14,905–15,801]	36,976 [35,899–37,917]	39,516 [38,064–41,185]	23,775 [23,005–24,661]	63,291 [61,542–65,156]	7,193 [6,949–7,417]	4,393 [4,278–4,500]	11,585 [11,283–11,834]	12,013 [11,565–12,495]	6,434 [6,181–6,683]	18,446 [17,879–19,013]
Oceania	31 [25–41]	19 [16–28]	51 [44–61]	75 [63–94]	47 [40–60]	121 [109–140]	11 [9–16]	5 [4–7]	16 [13–21]	27 [22–35]	13 [11–15]	40 [34–48]
Central sub-Saharan Africa	260 [199–371]	248 [166–430]	507 [380–759]	598 [513–684]	496 [426–593]	1,094 [1,006–1,200]	121 [101–144]	88 [72–124]	209 [182–250]	292 [227–357]	182 [156–212]	474 [396–553]
Eastern sub-Saharan Africa	971 [776–1,184]	751 [619–1,032]	1,723 [1,485–2,114]	2,211 [1,630–2,706]	1,727 [1,386–2,076]	3,938 [3,123–4,646]	423 [344–508]	292 [242–384]	715 [617–846]	996 [809–1,177]	629 [535–727]	1,625 [1,379–1,855]
Central Asia	1,274 [1,086–1,411]	928 [868–982]	2,202 [1,973–2,360]	2,332 [2,193–2,451]	1,569 [1,464–1,660]	3,901 [3,693–4,061]	523 [435–594]	295 [267–322]	819 [712–897]	904 [812–1,004]	467 [421–516]	1,372 [1,256–1,485]
Southern sub-Saharan Africa	416 [348–473]	347 [293–389]	762 [652–845]	1,000 [892–1,083]	774 [697–845]	1,774 [1,611–1,901]	171 [138–196]	105 [85–119]	276 [229–310]	389 [350–426]	214 [190–235]	603 [551–651]
Western sub-Saharan Africa	794 [692–933]	778 [672–952]	1,572 [1,398–1,830]	2,254 [2,047–2,420]	1,814 [1,644–1,985]	4,069 [3,845–4,310]	380 [330–440]	335 [294–395]	715 [637–819]	1,028 [893–1,179]	639 [560–709]	1,667 [1,524–1,826]
East Asia	6,859 [6,441–8,003]	6,607 [6,327–6,980]	13,467 [12,977–14,660]	29,524 [26,871–30,836]	17,215 [16,085–18,325]	46,739 [43,375–48,820]	3,033 [2,834–3,609]	2,184 [2,054–2,381]	5,217 [4,964–5,892]	11,718 [10,842–12,404]	5,238 [4,898–5,579]	16,955 [15,938–17,772]
South Asia	3,982 [3,337–4,524]	2,514 [2,325–3,111]	6,496 [5,870–6,961]	11,333 [10,704–11,874]	6,058 [5,880–6,263]	17,391 [16,760–17,991]	1,890 [1,522–2,226]	978 [800–1,158]	2,868 [2,424–3,223]	4,983 [4,662–5,313]	2,197 [2,030–2,362]	7,181 [6,812–7,577]

Table 1 (*continued*)

Table 1 (*continued*)

Location	Incident cases, global and regional						Death cases, global and regional					
	1990			2016			1990			2016		
	Male	Female	Both	Male	Female	Both	Male	Female	Both	Male	Female	Both
Southeast Asia	2,917 [2,706–3,190]	3,011 [2,661–3,590]	5,927 [5,513–6,458]	9,380 [8,430–10,072]	6,945 [6,403–7,696]	16,325 [15,401–17,474]	1,160 [1,049–1,286]	1,016 [927–1,124]	2,176 [2,056–2,299]	3,726 [3,376–4,109]	2,283 [2,055–2,591]	6,009 [5,578–6,577]
Australasia	949 [885–1015]	581 [546–619]	1,530 [1,455–1,601]	2,429 [2,201–2,683]	1,205 [1,107–1,308]	3,634 [3,384–3,914]	444 [415–474]	296 [276–316]	739 [705–776]	899 [814–992]	501 [452–556]	1,400 [1,301–1,504]
Caribbean	476 [446–515]	885 [810–1,019]	1,361 [1,274–1,513]	919 [872–1,013]	730 [692–771]	1,649 [1,588–1,741]	218 [205–234]	319 [298–359]	537 [511–576]	391 [361–435]	248 [227–269]	639 [602–684]
Central Europe	5,889 [5,691–6,122]	4,263 [4,054–4,476]	10,152 [9,865–10,489]	10,509 [9,761–11,172]	6,951 [6,513–7,358]	17,459 [16,405–18,283]	2,945 [2,831–3,086]	1,753 [1,678–1,830]	4,698 [4,554–4,865]	5,284 [4,880–5,653]	2,956 [2,732–3,191]	8,239 [7,747–8,713]
Eastern Europe	12,124 [9,948–14,053]	8,413 [7,555–9,267]	20,537 [17,891–22,736]	19,906 [17,715–22,685]	13,853 [12,499–15,406]	33,759 [30,867–36,989]	4,322 [3,581–4,987]	2,478 [2,210–2,731]	6,800 [5,920–7,561]	7,924 [5,967–10,246]	4,703 [3,351–6,658]	12,627 [10,110–15,500]

Data in the parentheses indicates 95% uncertainty interval (95% UI). SDI, Sociodemographic index (a summary indicator of income per capita, educational attainment, and fertility).

Table 2 Global and regional age-standardized kidney cancer incidence and death rates with 95% uncertainty interval and percent change by geography, gender and SDI between 1990 and 2016

Location	Sex	Age-standardized incidence rates per 100,000			Age-standardized death rates per 100,000		
		1990	2016	Change (%)	1990	2016	Change (%)
Global	Both	4.48 (4.38–4.58)	4.97 (4.81–5.09)	10.94	1.93(1.89-1.98)	2.00(1.93-2.06)	3.63
	Male	5.67 (5.45–5.88)	6.54 (6.28–6.73)	15.34	2.67 (2.56–2.76)	2.88 (2.77–2.99)	7.87
	Female	3.52 (3.46–3.62)	3.62 (3.50–3.71)	2.84	1.37 (1.35–1.40)	1.27 (1.22–1.34)	–7.3
High SDI	Both	9.05 (8.89–9.19)	10.08 (9.72–10.39)	11.38	3.51 (3.45–3.56)	3.47 (3.33–3.59)	–1.14
	Male	12.36 (12.06–12.64)	13.67 (13.07–14.24)	10.6	5.24 (5.13–5.53)	5.17 (4.90–5.39)	–1.34
	Female	6.47 (6.34–6.60)	6.99 (6.73–7.21)	8.04	2.26 (2.22–2.30)	2.10 (2.02–2.19)	–7.08
High-middle SDI	Both	5.39 (5.03–5.69)	6.30 (6.00–6.58)	16.88	2.09 (1.96–2.20)	2.36 (2.15–2.59)	12.92
	Male	6.82 (6.15–7.43)	8.27 (7.77–8.79)	21.26	2.97 (2.71–3.20)	3.48 (3.11–3.88)	17.17
	Female	4.28 (4.08–4.49)	4.65 (4.40–4.93)	8.64	1.45 (1.39–1.52)	1.47 (1.27–1.75)	13.79
Middle SDI	Both	1.88 (1.83–1.98)	3.00 (2.89–3.07)	59.57	0.91 (0.88–0.96)	1.26 (1.20–1.31)	38.46
	Male	2.05 (1.95–2.25)	3.78 (3.56–3.92)	84.39	1.12 (1.06–1.23)	1.78 (1.67–1.88)	58.93
	Female	1.75 (1.67–1.83)	2.30 (2.22–2.36)	31.43	0.73 (0.71–0.76)	0.80 (0.77–0.83)	9.59
Low-middle SDI	Both	1.16 (1.05–1.27)	1.65 (1.59–1.71)	42.24	0.60 (0.51–0.67)	0.75 (0.71–0.79)	25.00
	Male	1.35 (1.15–1.58)	2.09 (1.97–2.20)	54.81	0.74 (0.59–0.88)	1.03 (0.96–1.10)	39.19
	Female	0.96 (0.94–1.17)	1.25 (1.22–1.30)	30.21	0.48 (0.41–0.54)	0.51 (0.48–0.54)	6.25
Low SDI	Both	1.23 (1.13–1.37)	1.47 (1.32–1.61)	19.51	0.77 (0.67–0.84)	0.88 (0.78–0.96)	14.29
	Male	1.38 (1.20–1.59)	1.70 (1.46–1.93)	23.19	0.91 (0.75–1.05)	1.13 (0.96–1.27)	24.18
	Female	1.11 (1.01–1.42)	1.25 (1.17–1.34)	12.61	0.65 (0.57–0.78)	0.66 (0.60–0.72)	1.54
High-income Asia Pacific	Both	3.55 (3.48–3.70)	5.10 (4.65–5.37)	43.66	1.76 (1.72–1.81)	2.13 (1.91–2.31)	21.02
	Male	5.15 (5.02–5.45)	7.30 (6.55–7.74)	41.75	2.74 (2.66–2.86)	3.38 (2.97–3.75)	23.36
	Female	2.32 (2.26–2.38)	3.22 (2.96–3.41)	38.79	1.04 (1.01–1.07)	1.14 (1.04–1.26)	9.62
Western Europe	Both	8.87 (8.64–9.11)	9.73 (9.15–10.18)	9.7	3.81 (3.73–3.89)	3.72 (3.52–3.91)	–2.36
	Male	12.48 (12.04–12.93)	13.41 (12.45–14.22)	7.45	5.74 (5.58–5.92)	5.58 (5.2–5.9)	–2.79
	Female	6.08 (5.87–6.30)	6.56 (6.15–6.90)	7.89	2.45 (2.39–2.52)	2.25 (2.12–2.38)	–8.16
Andean Latin America	Both	3.75 (3.53–4.02)	4.16 (3.90–4.39)	10.93	1.91 (1.78–2.05)	1.92 (1.68–2.17)	0.52
	Male	3.42 (3.17–3.70)	4.97 (4.51–5.40)	45.32	1.99 (1.8–2.2)	2.57 (2.11–3.07)	29.15
	Female	4.09 (3.77–4.59)	3.47 (3.24–3.73)	–15.16	1.86 (1.68–2.09)	1.37 (1.16–1.63)	–26.34
Central Latin America	Both	3.47 (3.39–3.54)	5.23 (5.08–5.38)	50.72	1.75 (1.7–1.8)	2.12 (2.03–2.22)	21.14
	Male	3.68 (3.58–3.78)	6.28 (6.01–6.56)	70.65	2.06 (1.99–2.14)	2.85 (2.68–3.04)	38.35
	Female	3.32 (3.21–3.42)	4.32 (4.19–4.45)	30.12	1.49 (1.44–1.55)	1.50 (1.43–1.58)	0.67
Southern Latin America	Both	11.79 (11.32–12.26)	10.73 (10.19–11.27)	–8.99	5.49 (5.26–5.74)	4.56 (4.13–5.01)	–16.94
	Male	10.97 (10.45–11.54)	15.13 (14.12–16.11)	37.92	5.68 (5.35–6.05)	7.14 (6.3–8.06)	25.70
	Female	12.57 (11.88–13.28)	7.20 (6.76–7.72)	–42.72	5.36 (5.05–5.7)	2.63 (2.32–2.99)	–50.93

Table 2 (*continued*)

Table 2 (*continued*)

Location	Sex	Age-standardized incidence rates per 100,000			Age-standardized death rates per 100,000		
		1990	2016	Change (%)	1990	2016	Change (%)
Tropical Latin America	Both	2.91 (2.84–2.99)	4.63 (4.51–4.75)	59.11	1.49 (1.44–1.54)	1.95 (1.87–2.03)	30.87
	Male	3.56 (3.43–3.69)	5.90 (5.66–6.13)	65.73	2.04 (1.94–2.13)	2.84 (2.67–3.01)	39.22
	Female	2.42 (2.34–2.52)	3.64 (3.52–3.75)	50.41	1.08 (1.03–1.12)	1.28 (1.21–1.35)	18.52
North Africa and Middle East	Both	1.83 (1.65–2.02)	2.73 (2.57–2.93)	49.18	0.98 (0.84–1.1)	1.17 (1.07–1.29)	19.39
	Male	2.26 (1.97–2.71)	3.47 (3.14–3.81)	53.54	1.32 (1.08–1.59)	1.67 (1.47–1.88)	26.52
	Female	1.44 (1.33–1.78)	2.04 (1.85–2.18)	41.67	0.68 (0.59–0.8)	0.73 (0.65–0.81)	7.35
High-income North America	Both	12.28 (11.92–12.59)	12.77 (12.4–13.15)	3.99	3.72 (3.62–3.8)	3.49 (3.38–3.6)	–6.18
	Male	16.12 (15.45–16.7)	16.96 (16.34–17.69)	5.21	5.47 (5.28–5.64)	5.08 (4.89–5.28)	–7.13
	Female	9.24 (8.95–9.50)	9.09 (8.77–9.45)	–1.62	2.41 (2.35–2.47)	2.17 (2.08–2.25)	–9.96
Oceania	Both	1.36 (1.14–1.67)	1.63 (1.47–1.90)	19.85	0.61 (0.48–0.79)	0.66 (0.56–0.79)	8.20
	Male	1.88 (1.49–2.52)	2.26 (1.89–2.83)	20.21	0.91 (0.67–1.25)	1.00 (0.80–1.29)	9.89
	Female	0.89 (0.78–1.16)	1.11 (0.99–1.35)	24.72	0.35 (0.29–0.43)	0.38 (0.33–0.44)	8.57
Central sub-Saharan Africa	Both	1.52 (1.38–1.74)	1.67 (1.42–1.93)	9.87	0.91 (0.75–1.05)	1.00 (0.77–1.21)	9.89
	Male	1.85 (1.62–2.15)	2.10 (1.61–2.59)	13.51	1.21 (0.94–1.50)	1.36 (0.98–1.74)	12.40
	Female	1.27 (1.07–1.76)	1.32 (1.19–1.46)	3.94	0.68 (0.56–0.83)	0.69 (0.57–0.84)	1.47
Eastern sub-Saharan Africa	Both	1.16 (1.06–1.31)	1.46 (1.29–1.59)	25.86	0.72 (0.65–0.8)	0.85 (0.77–0.94)	18.06
	Male	1.32 (1.09–1.49)	1.70 (1.41–1.89)	28.79	0.86 (0.72–0.98)	1.09 (0.94–1.23)	26.74
	Female	1.02 (0.89–1.31)	1.24 (1.10–1.38)	21.57	0.60 (0.51–0.75)	0.64 (0.57–0.72)	6.67
Central Asia	Both	4.35 (3.82–4.71)	5.23 (4.96–5.44)	20.23	1.78 (1.53–1.96)	2.01 (1.85–2.17)	12.92
	Male	5.9 (4.95–6.57)	7.02 (6.62–7.37)	18.98	2.75 (2.28–3.11)	3.04 (2.75–3.36)	10.55
	Female	3.21 (2.93–3.42)	3.85 (3.60–4.07)	19.94	1.10 (0.98–1.21)	1.23 (1.11–1.36)	11.82
Southern sub-Saharan Africa	Both	2.14 (1.81–2.39)	3.14 (2.86–3.34)	46.73	0.97 (0.79–1.1)	1.28 (1.17–1.38)	31.96
	Male	2.78 (2.26–3.19)	4.26 (3.80–4.60)	53.24	1.42 (1.11–1.65)	2.02 (1.83–2.21)	42.25
	Female	1.65 (.14–1.84)	2.35 (2.13–2.54)	42.42	0.63 (0.51–0.72)	0.77 (0.68–0.85)	22.22
Western sub-Saharan Africa	Both	18.58 (11.92–23.73)	22.83 (13.45–27.5)	22.87	0.77 (0.70–0.85)	0.96 (0.87–1.06)	24.68
	Male	1.33 (1.2–1.46)	1.97 (1.78–2.12)	48.12	0.90 (0.79–1.02)	1.28 (1.10–1.48)	42.22
	Female	1.11 (1.01–1.28)	1.35 (1.25–1.43)	21.62	0.67 (0.59–0.76)	0.68 (0.59–0.76)	1.49
East Asia	Both	1.5 (1.44–1.64)	2.92 (2.70–3.06)	94.67	0.67 (0.63–0.76)	1.11 (1.04–1.16)	65.67
	Male	1.61 (1.51–1.9)	3.66 (3.31–3.82)	127.33	0.83 (0.77–1.01)	1.58 (1.46–1.67)	90.36
	Female	1.42 (1.37–1.49)	2.25 (2.09–2.40)	58.45	0.54 (0.51–0.58)	0.68 (0.64–0.73)	25.93
South Asia	Both	0.97 (0.86–1.07)	1.34 (1.29–1.39)	38.14	0.90 (0.84–0.96)	1.21 (1.12–1.33)	34.44
	Male	1.22 (1.03–1.42)	1.79 (1.69–1.87)	46.72	1.07 (0.95–1.2)	1.65 (1.50–1.83)	54.21
	Female	0.72 (0.67–0.85)	0.91 (0.88–0.94)	26.39	0.77 (0.71–0.84)	0.85 (0.77–0.97)	10.39

Table 2 (*continued*)

Table 2 (*continued*)

Location	Sex	Age-standardized incidence rates per 100,000			Age-standardized death rates per 100,000		
		1990	2016	Change (%)	1990	2016	Change (%)
Southeast Asia	Both	2.02 (1.93–2.12)	2.92 (2.75–3.12)	44.55	0.90 (0.84–0.96)	1.21 (1.12–1.33)	34.44
	Male	2.23 (2.01–2.49)	3.63 (3.25–3.89)	62.78	1.07 (0.95–1.20)	1.65 (1.50–1.83)	54.21
	Female	1.86 (1.7–2.11)	2.33 (2.16–2.58)	25.27	0.77 (0.71–0.84)	0.85 (0.77–0.97)	10.39
Australasia	Both	7.18 (6.84–7.51)	9.34 (8.68–10.07)	30.08	3.45 (3.29–3.61)	3.32 (3.08–3.57)	–3.77
	Male	9.72 (9.08–10.35)	13.01 (11.81–14.34)	33.85	4.71 (4.42–5.01)	4.65 (4.22–5.13)	–1.27
	Female	5.09 (4.77–5.44)	5.96 (5.47–6.47)	17.09	2.46 (2.3–2.62)	2.16 (1.94–2.39)	–12.20
Caribbean	Both	4.87 (4.62–5.28)	3.66 (3.53–3.87)	–24.85	2.11 (2.01–2.23)	1.44 (1.36–1.54)	–31.75
	Male	3.59 (3.41–3.8)	4.30 (4.08–4.74)	19.78	1.82 (1.71–1.95)	1.91 (1.76–2.11)	4.95
	Female	6.1 (5.66–6.84)	3.11 (2.95–3.28)	–49.02	2.38 (2.24–2.62)	1.05 (0.96–1.14)	–55.88
Central Europe	Both	7.62 (7.40–7.87)	9.98 (9.36–10.45)	30.97	3.53 (3.43–3.65)	4.44 (4.17–4.70)	28.77
	Male	9.94 (9.61–10.31)	13.46 (12.47–14.27)	35.41	5.16 (4.97–5.40)	6.72 (6.23–7.19)	33.15
	Female	5.79 (5.50–6.08)	7.17 (6.70–7.60)	23.83	2.31 (2.22–2.41)	2.69 (2.49–2.90)	20.33
Eastern Europe	Both	8.23 (7.20–9.08)	11.37 (10.42–12.38)	38.15	2.71 (2.37–3.00)	4.09 (3.27–5.01)	50.92
	Male	12.38 (10.37–14.18)	16.58 (14.86–18.80)	33.93	4.80 (4.07–5.48)	6.81 (5.18–8.67)	41.88
	Female	5.67 (5.10–6.22)	7.88 (7.11–8.74)	38.98	1.56 (1.40–1.71)	2.40 (1.71–3.39)	53.85

Data in the parentheses indicates 95% uncertainty interval (95% UI). SDI, Sociodemographic index (a summary indicator of income per capita, educational attainment, and fertility).

Projections of kidney cancer incidence and mortality from 2017 to 2030

Based on the analytical period, we predicted the future trends of incidence and mortality rates of kidney cancer. As a result of these trends, by 2030, kidney cancer in both sexes are projected to increase substantially in high SDI, followed by middle SDI, low-middle SDI, and low SDI countries, while the trends in incidence rates will remain stable globally and in high-middle SDI countries. Furthermore, high SDI and low SDI countries will also have increased mortality rates from kidney cancers, while decreased mortality rates from kidney cancer will be observed in high-middle SDI countries. Globally, the trends in deaths due to kidney cancer will remain stable. The estimated risk of kidney cancer for males within the age of 30 and 70 is around 0.79% compared to 0.41% for female. Similar results can be seen in other age intervals and in SDI countries. In other words, the probability of developing kidney cancer is generally higher in male than in female (*Table 3* and *Figure 4*).

Discussion

Globally, over-time trends of kidney cancer incidence and death rates are increasing significantly, especially in older age groups and high SDI countries where life expectancy gains are greater. Worldwide, incident cases of kidney cancer increased by nearly 102% from 1990 (169,514; 95% UI, 166,246-173,338) to 2016 (342,100; 95% UI, 330,759–349,934). Among all SDI countries and most regions, we found the similar increased over-time trends in kidney cancer incidence rates from 1990 and 2016. There were 131,800 (95% UI, 127,335–136,185) death cases from kidney cancer in 2016, nearly 2.0-fold compared to the number in 1990 (67,306; 95%UI, 65,806–68,836).

The highest ASIR in 2016 was found in high SDI countries. The highest ASDR was found in middle SDI countries, while ASDR decreased significantly in regions with high kidney cancer burdens including Southern Latin America as well as the Caribbean. The clinical outcomes of kidney cancer depend on health care expenditures as well as early precise diagnosis and treatment (13). Risk

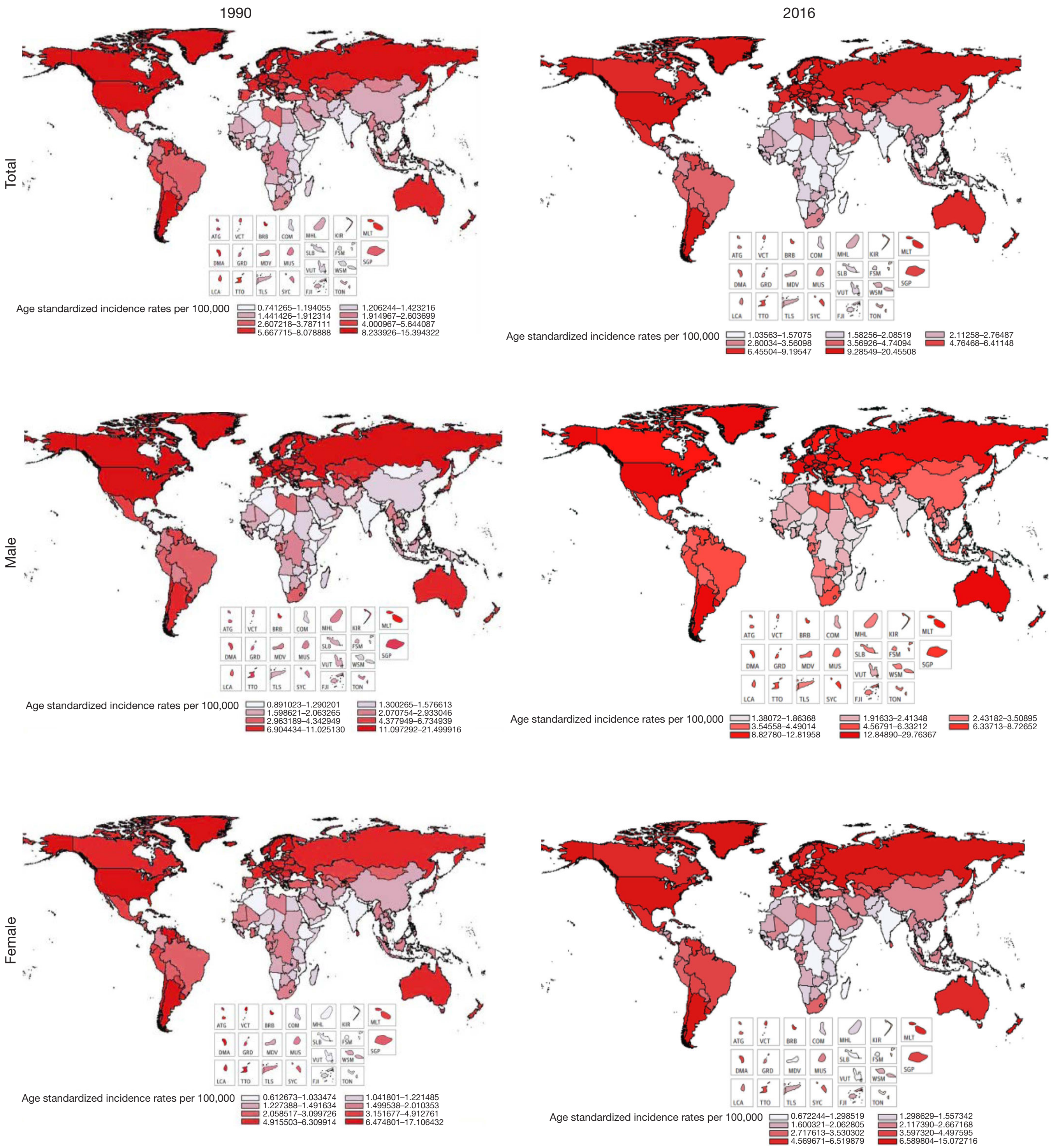

Figure 1 Global and regional kidney cancer ASIR by geography and gender, 1990 and 2016. ASIR, age-standardized incidence rate; ATG, Antigua and Barbuda; VCT, Saint Vincent and the Grenadines; BRB, Barbados; COM, Comoros; MHL, Marshall Islands; KIR, Kiribati; MLT, Malta; DMA, Dominica; GRD, Grenada; MDV, Maldives; MUS, Mauritius; SLB, Solomon Islands; FSM, Federated States of Micronesia; VUT, Vanuatu; WSM, Samoa. SGP, Singapore; LCA, Saint Lucia; TTO, Trinidad and Tobago; TLS, Timor-Leste; SYC, Seychelles; FJI, Fiji; TON, Tonga.

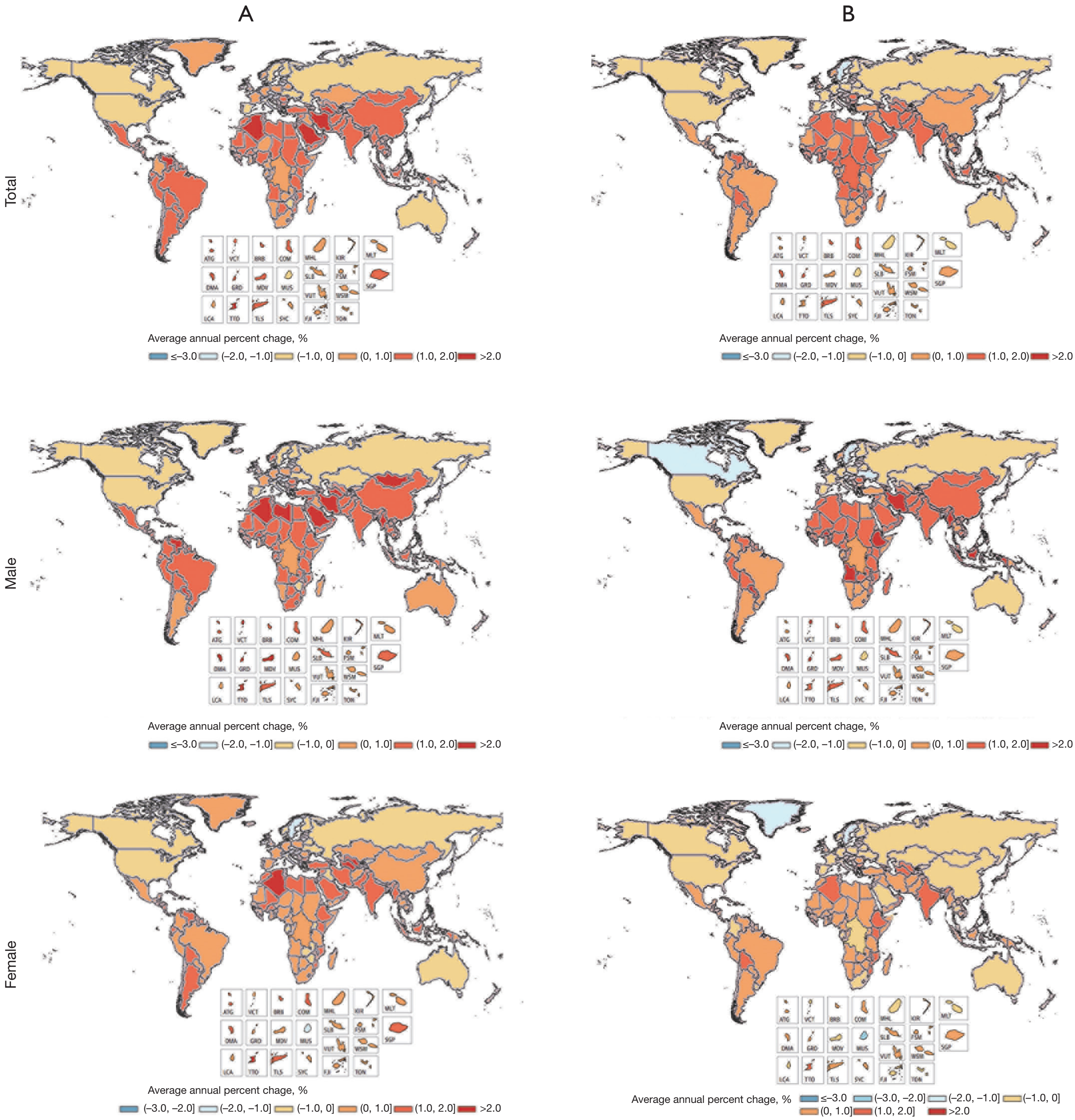

Figure 2 Global and regional average annual percent change in age-standardized incidence and death rates for kidney cancer by geography and gender, 1990–2016. (A) Average annual percent change in age-standardized incidence rates for kidney cancer by geography and gender, 1990–2016; (B) average annual percent change in age-standardized death rates for kidney cancer by geography and gender, 1990–2016. ATG, Antigua and Barbuda; VCT, Saint Vincent and the Grenadines; BRB, Barbados; COM, Comoros; MHL, Marshall Islands; KIR, Kiribati; MLT, Malta; DMA, Dominica; GRD, Grenada; MDV, Maldives; MUS, Mauritius; SLB, Solomon Islands; FSM, Federated States of Micronesia; VUT, Vanuatu; WSM, Samoa. SGP, Singapore; LCA, Saint Lucia; TTO, Trinidad and Tobago; TLS, Timor-Leste; SYC, Seychelles; FJI, Fiji; TON, Tonga.

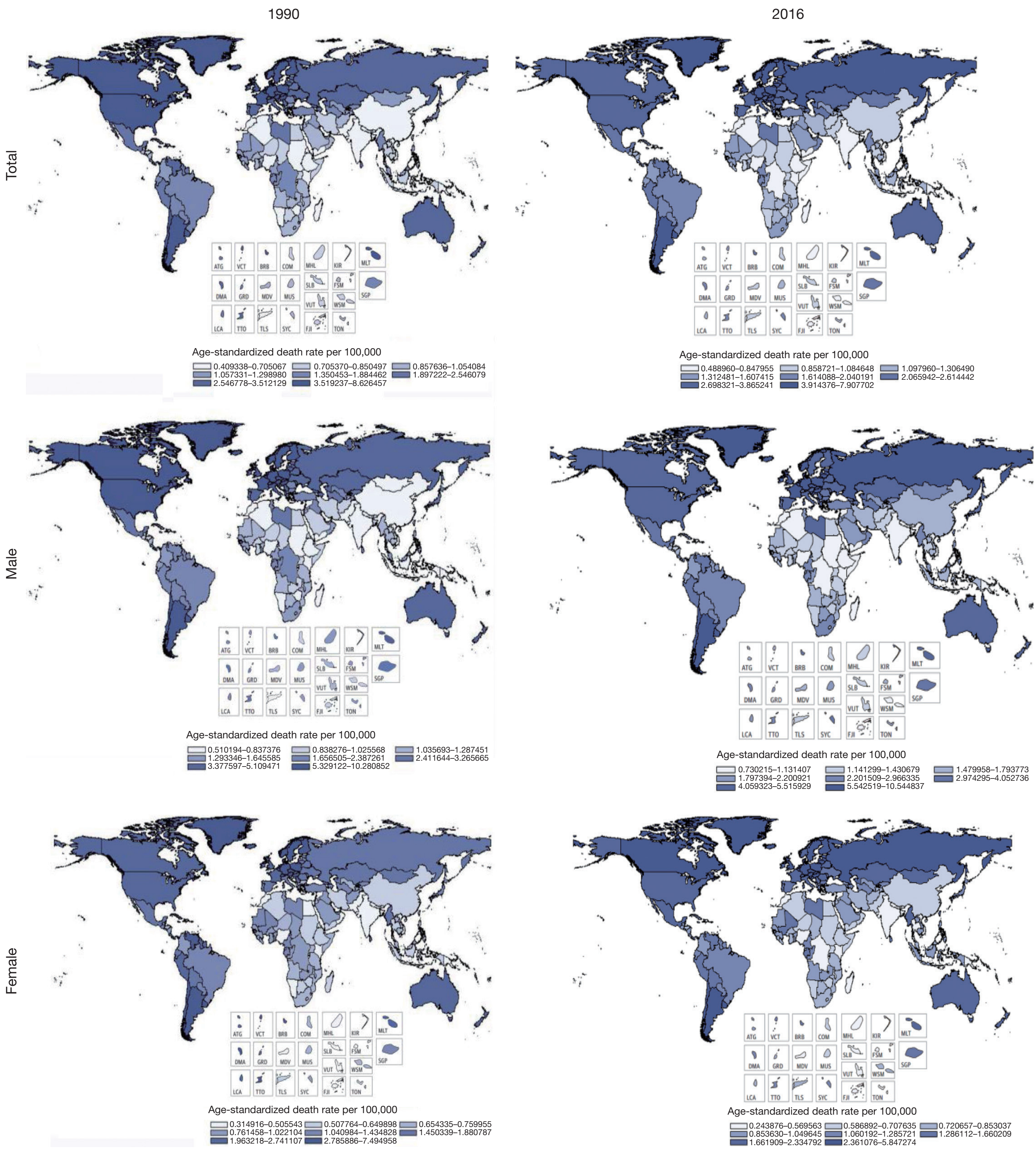

Figure 3 Global and regional kidney cancer ASDR by geography and gender, 1990 and 2016. ASDR, age-standardized death rate; ATG, Antigua and Barbuda; VCT, Saint Vincent and the Grenadines; BRB, Barbados; COM, Comoros; MHL, Marshall Islands; KIR, Kiribati; MLT, Malta; DMA, Dominica; GRD, Grenada; MDV, Maldives; MUS, Mauritius; SLB, Solomon Islands; FSM, Federated States of Micronesia; VUT, Vanuatu; WSM, Samoa. SGP, Singapore; LCA, Saint Lucia; TTO, Trinidad and Tobago; TLS, Timor-Leste; SYC, Seychelles; FJI, Fiji; TON, Tonga.

Table 3 Probability of developing kidney cancer within selected age intervals, global, and by SDI quintile, by sex, 2006–2016 in % (odds)

Location/ SDI quintile	Birth to age 49		Age 50 to 59		Age 60 to 69		Age 70 to 79		Age 30 to 70		Birth to age 79	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Global	0.07 (1 in 1,373)	0.05 (1 in 1,963)	0.13 (1 in 768)	0.06 (1 in 1,590)	0.24 (1 in 424)	0.12 (1 in 823)	0.36 (1 in 276)	0.19 (1 in 522)	0.79 (1 in 127)	0.41 (1 in 241)	0.80 (1 in 125)	0.43 (1 in 235)
High-middle SDI	0.10 (1 in 958)	0.07 (1 in 1,376)	0.19 (1 in 520)	0.09 (1 in 1,141)	0.33 (1 in 307)	0.17 (1 in 593)	0.39 (1 in 255)	0.22 (1 in 446)	1.00 (1 in 100)	0.53 (1 in 188)	1.01 (1 in 99)	0.55 (1 in 181)
High SDI	0.16 (1 in 639)	0.10 (1 in 1,029)	0.29 (1 in 349)	0.13 (1 in 760)	0.52 (1 in 194)	0.25 (1 in 408)	0.75 (1 in 133)	0.38 (1 in 263)	1.69 (1 in 59)	0.83 (1 in 120)	1.70 (1 in 59)	0.85 (1 in 117)
Low-middle SDI	0.03 (1 in 3,050)	0.03 (1 in 3,861)	0.05 (1 in 2,185)	0.03 (1 in 3,849)	0.07 (1 in 1,378)	0.04 (1 in 2,557)	0.09 (1 in 1,088)	0.04 (1 in 2,262)	0.24 (1 in 421)	0.13 (1 in 774)	0.24 (1 in 412)	0.14 (1 in 740)
Low SDI	0.03 (1 in 3,890)	0.03 (1 in 3,997)	0.04 (1 in 2,788)	0.03 (1 in 3,740)	0.05 (1 in 1,925)	0.04 (1 in 2,816)	0.07 (1 in 1,437)	0.04 (1 in 2,681)	0.18 (1 in 564)	0.12 (1 in 847)	0.18 (1 in 547)	0.12 (1 in 803)
Middle SDI	0.06 (1 in 1,611)	0.05 (1 in 2,070)	0.08 (1 in 1,235)	0.04 (1 in 2,467)	0.12 (1 in 832)	0.07 (1 in 1,479)	0.18 (1 in 563)	0.09 (1 in 1,127)	0.43 (1 in 233)	0.23 (1 in 434)	0.44 (1 in 227)	0.24 (1 in 408)

Data in the parentheses indicates 95% uncertainty interval (95% UI). SDI, Sociodemographic index (a summary indicator of income per capita, educational attainment, and fertility).

of developing kidney cancer and trends of deaths were evaluated for both sexes, and most incident and death rates were greater in males than females across all SDI countries and most regions. Overall, the burden of kidney cancer is significantly higher in males than in females.

Life expectancy and population growth account for a large proportion of the increase in the incidence of kidney cancer (18). However, over-time trends of kidney cancer incidence and the difference of incident rates among variable countries may be influenced by some other elements. For instance, poor lifestyles of smoking, and obesity as well as excess body mass index (BMI: defined as 25 kg/m^2 or greater) have been identified as crucial contributor of kidney cancer (19). In higher-income countries, the increase in kidney cancer incident cases may partially as a result of the increase in the occasional detection of abnormal kidney changes when performing abdominal imaging for diseases of other systems (20). Multi-factors have been found contributed to the increased mortality rates of kidney cancer, such as, tobacco smoking-related and rising obesity-attributed deaths, high BMI, hypertension, or pharmacologic control of hypertension. In these years, the role of gene-gene and gene-environmental functions and/or interactions have received increasing attention in disease development and progress.

Kidney cancer incidence and deaths will substantially increase at a global level, while decreased trends will also be found in some SDI countries and regions. By 2030, kidney cancers in both sexes are projected to increase substantially in high SDI, followed by middle SDI, low-middle SDI, and low SDI countries, while the over-time trends of kidney cancer incidence rates will remain stable globally and in high-middle SDI countries. Furthermore, high SDI and low SDI countries will also have increased mortality rates from kidney cancers, while decreased mortality rates from kidney cancer will be observed in high-middle SDI countries. Globally, the trends in deaths due to kidney cancer will remain stable. Due to the population expansion and ageing, the time trends in kidney cancer incidence and mortality is substantially increasing. Reducing the risk of developing kidney cancer is a challenge for our doctors and will require commitments of all sectors of society. The time trends presented in this study will be helpful particularly in health care resource allocation planning as a window for the future, which is a necessary condition for notification of health policy, adjust health care policy, screen guidelines accordingly, and make resource allocation decisions. What had been found in this study allow for insight into future

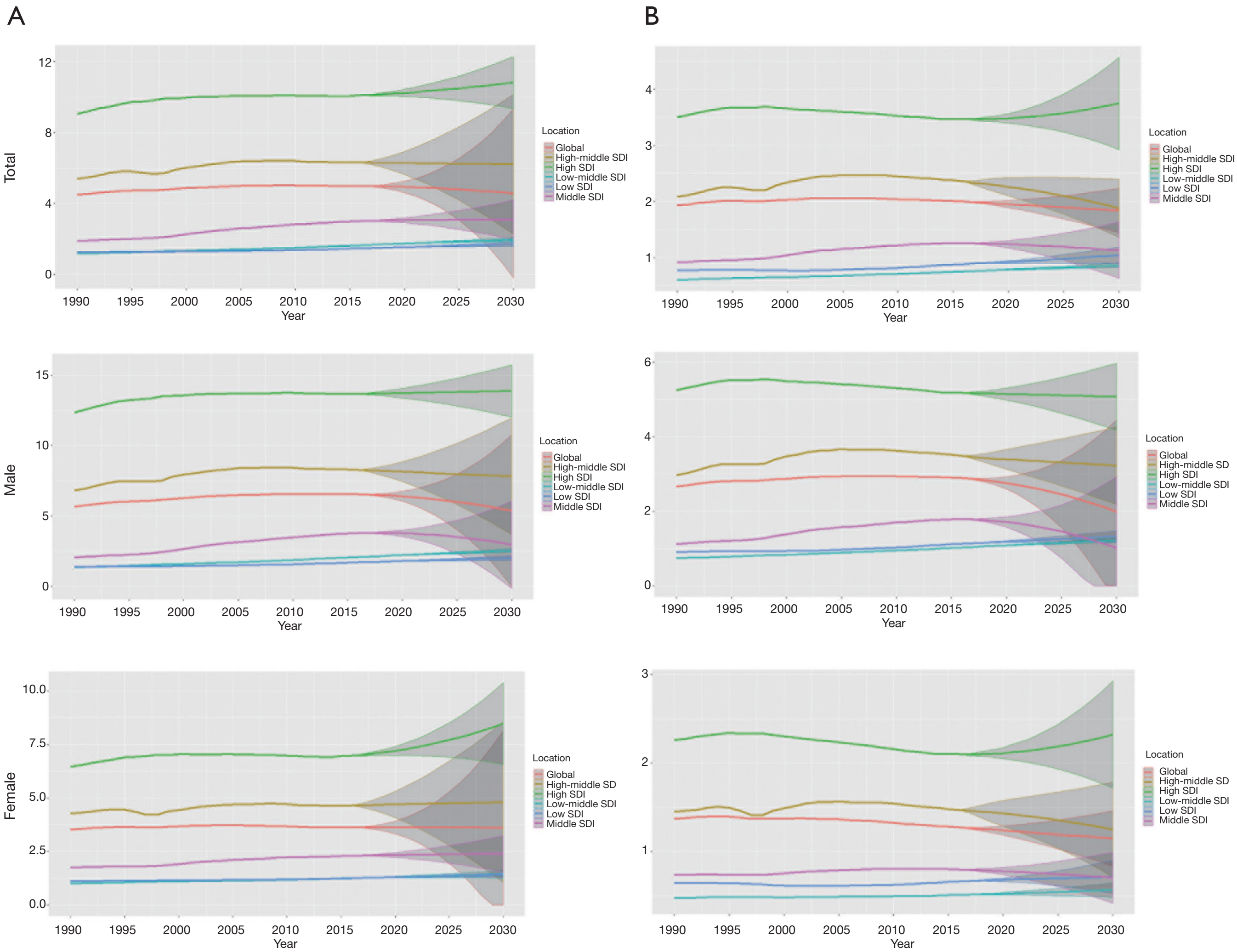

Figure 4 Global and regional trends and predictions in age-standardized incidence and death rates for kidney cancer by SDI quintile, 1990–2030. (A) Trends and predictions in age-standardized incidence rates for kidney cancer by SDI quintile, 1990–2030; (B) trends and predictions in age-standardized death rates for kidney cancer by SDI quintile, 1990–2030. SDI, sociodemographic index (a summary indicator of income per capita, educational attainment, and fertility).

global kidney cancer demands based on observed trends.

This study also has some limitations, data from GBD are reported by using traditional epidemiologic methods, which often have a 3-year delay main due to the data collection. The trends in kidney cancer incidence and mortality in the recent three years may be different from the results we predicted, resulting in a slight deviation in the predictions afterwards. On the other hand, our results are only predicted until 2030 and more data are required due to the need for accuracy to make longer-term predictions.

Conclusions

The incidence and mortality rate of kidney cancer have uniformly increased among different countries since 1990. By 2030, the incidence and mortality of kidney cancer will be steadily increasing globally. An epidemiology reference for policy makers is absolutely necessary to adjust health care policy, screen guidelines, and make resource allocation decisions. The appropriate allocation of limited resources is also imperative for kidney cancer prevention, screening, and treatment. The above results show that the future incidence of kidney cancer will grow continuously by 2030 especially in high SDI countries, middle SDI, low-middle SDI, and low SDI countries, where medical workers and researchers should intensively focus on the health care systems to ensure whether previously informed policies are adapted to the future incidence trend of kidney cancer in their countries.

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/tau.2020.02.23). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Table S1 Number of site-years for kidney cancer mortality data

Cause	VR GBD 2015	VR GBD 2016	VR change GBD 2015 to GBD 2016	VA GBD 2015	VA GBD 2016	VA change GBD 2015 to GBD 2016	CR GBD 2015	CR GBD 2016	CR change GBD 2015 to GBD 2016	Total GBD 2015	Total GBD 2016	Total change GBD 2015 to GBD 2016
Kidney cancer	10,095	16,010	59%	–	–	–	2,387	2,716	14%	12,482	18,726	50%

GBD, Global Burden of Disease Study; VR, vital registration system data; VA, verbal autopsy data; CR, cancer registry data.

Table S2 Covariates selected for CODEm for GBD of kidney cancer and expected direction of covariate

Cause	Sex	Age start	Age end	Direction	Covariate
Kidney cancer	Male	0–6 days	95+ years	1	Alcohol (liters per capita)
Kidney cancer	Male	0–6 days	95+ years	1	Cumulative cigarettes (10 years)
Kidney cancer	Male	0–6 days	95+ years	1	Cumulative cigarettes (15 years)
Kidney cancer	Male	0–6 days	95+ years	1	Cumulative cigarettes (5 years)
Kidney cancer	Male	0–6 days	95+ years	1	Diabetes age-standardized prevalence (proportion)
Kidney cancer	Male	0–6 days	95+ years	–1	Education (years per capita)
Kidney cancer	Male	0–6 days	95+ years	–1	Health System Access 2 (unitless)
Kidney cancer	Male	0–6 days	95+ years	0	LDI (I$ per capita)
Kidney cancer	Male	0–6 days	95+ years	1	Mean BMI
Kidney cancer	Male	0–6 days	95+ years	1	Systolic blood pressure (mmHg)
Kidney cancer	Male	0–6 days	95+ years	1	Smoking prevalence
Kidney cancer	Male	0–6 days	95+ years	1	Log-transformed SEV scalar: Kidney C
Kidney cancer	Male	0–6 days	95+ years	0	Sociodemographic index
Kidney cancer	Female	0–6 days	95+ years	1	Alcohol (liters per capita)
Kidney cancer	Female	0–6 days	95+ years	1	Cumulative cigarettes (10 years)
Kidney cancer	Female	0–6 days	95+ years	1	Cumulative cigarettes (15 years)
Kidney cancer	Female	0–6 days	95+ years	1	Cumulative cigarettes (5 years)
Kidney cancer	Female	0–6 days	95+ years	1	Diabetes age-standardized prevalence (proportion)
Kidney cancer	Female	0–6 days	95+ years	–1	Education (years per capita)
Kidney cancer	Female	0–6 days	95+ years	–1	Health System Access 2 (unitless)
Kidney cancer	Female	0–6 days	95+ years	–1	LDI (I$ per capita)
Kidney cancer	Female	0–6 days	95+ years	1	Mean BMI
Kidney cancer	Female	0–6 days	95+ years	1	Systolic blood pressure (mmHg)
Kidney cancer	Female	0–6 days	95+ years	1	Smoking prevalence
Kidney cancer	Female	0–6 days	95+ years	0	Total fertility rate
Kidney cancer	Female	0–6 days	95+ years	1	Total calories (kcal per capita)
Kidney cancer	Female	0–6 days	95+ years	1	Log-transformed SEV scalar: Kidney C
Kidney cancer	Female	0–6 days	95+ years	1	Socio-demographic Index
Kidney cancer	Female	0–6 days	95+ years	0	LDI (I$ per capita)
Kidney cancer	Female	0–6 days	95+ years	0	Sociodemographic index

CODEm, cause of death ensemble model; GBD, Global Burden of Disease Study; BMI, body mass index.

Table S3 Comparison of GBD 2015 and GBD 2016 covariates used and level of covariates

Cause	Sex	Covariate	GBD 2015			GBD 2016		
			Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
Kidney cancer	Male	Cumulative cigarettes (10 years)	X			X		
Kidney cancer	Male	Cumulative cigarettes (15 years)	X			X		
Kidney cancer	Male	Sociodemographic index			X			X
Kidney cancer	Male	Cumulative cigarettes (5 years)	X			X		
Kidney cancer	Male	Alcohol (liters per capita)		X			X	
Kidney cancer	Male	Education (years per capita)			X			X
Kidney cancer	Male	LDI (I$ per capita)			X			X
Kidney cancer	Male	Health System Access 2 (unitless)		X			X	
Kidney cancer	Male	Diabetes age-standardized prevalence (proportion)		X			X	
Kidney cancer	Male	Smoking prevalence		X			X	
Kidney cancer	Male	Systolic blood pressure (mmHg)		X			X	
Kidney cancer	Male	Mean BMI	X			X		
Kidney cancer	Male	Log-transformed SEV scalar: Kidney C	X			X		
Kidney cancer	Female	Cumulative cigarettes (10 years)	X			X		
Kidney cancer	Female	Cumulative cigarettes (15 years)	X			X		
Kidney cancer	Female	Sociodemographic index			X			X
Kidney cancer	Female	Cumulative cigarettes (5 years)	X			X		
Kidney cancer	Female	Alcohol (liters per capita)		X			X	
Kidney cancer	Female	Total calories (kcal per capita)		X			X	
Kidney cancer	Female	Education (years per capita)			X			X
Kidney cancer	Female	LDI (I$ per capita)			X			X
Kidney cancer	Female	Health System Access 2 (unitless)		X			X	
Kidney cancer	Female	Diabetes age-standardized prevalence (proportion)		X			X	
Kidney cancer	Female	Total fertility rate			X			X
Kidney cancer	Female	Smoking prevalence		X			X	
Kidney cancer	Female	Systolic blood pressure (mmHg)		X			X	
Kidney cancer	Female	Mean BMI	X			X		
Kidney cancer	Female	Log-transformed SEV scalar: Kidney C	X			X		

GBD, Global Burden of Disease Study; BMI, body mass index.

Table S4 Results for CODEm model testing

Cause	Sex	Age start	Age end	Predictive validity					
				RMSE in	RMSE out	Trend in	Trend out	Coverage in	Coverage out
Kidney cancer [data rich]	Male	0–6 days	95+ years	0.241409	0.355526	0.19905	0.233492	0.999066	0.998706
Kidney cancer [data rich]	Female	0–6 days	95+ years	0.269859	0.399459	0.223989	0.265876	0.998886	0.997983
Kidney cancer [global]	Male	0–6 days	95+ years	0.280428	0.40437	0.224896	0.23264	0.999225	0.994304
Kidney cancer [global]	Female	0–6 days	95+ years	0.309672	0.434952	0.251863	0.260629	0.999065	0.992195

CODEm, cause of death ensemble model; RMSE, root mean square of errors.

Table S5 Percent change before and after Cod Correct by kidney cancer for all ages, both sexes combined, 2016

Cause	Cod Correct level	Percent change (%)
Kidney cancer	3	–1.83 (–3.18 to –0.23)

Table S6 Disability weights

Health state	Lay description	Estimate	Uncertainty interval
Cancer, diagnosis and primary therapy	Has pain, nausea, fatigue, weight loss and high anxiety	0.288	0.193–0.399
Cancer, controlled phase	Has a chronic disease that requires medication every day and causes some worry but minimal interference with daily activities	0.049	0.031–0.072
Cancer, metastatic	Has severe pain, extreme fatigue, weight loss and high anxiety	0.451	0.307–0.600
Terminal phase, with medication	Has lost a lot of weight and regularly uses strong medication to avoid constant pain. The person has no appetite, feels nauseous, and needs to spend most of the day in bed	0.540	0.377–0.687

Table S7 Decomposition analysis of kidney cancer incidence trends at the global and regional levels, and by SDI quintiles, both sexes, 2006 to 2016

Location	Incidence cases, No.		Expected incidence cases, 2016, No.		Change in incidence cases, 2006 to 2016, %			Overall change, %
	2006	2016	Given population growth alone	Given population growth and aging	Due to population growth	Due to change in age structure	Due to change in incidence rate	
Global	267,959 (263,949 to 271,723)	342,100 (330,759 to 349,934)	301,263	343,137	12.4	15.6	–0.4	27.7
High SDI	134,191 (131,951 to 136,091)	160,805 (154,689 to 165,708)	141,358	160,165	5.3	14	0.5	19.8
High-middle SDI	65,561 (63,121 to 68,051)	81,637 (77,842 to 85,447)	72,839	82,789	11.1	15.2	–1.8	24.5
Middle SDI	46,725 (45,882 to 47,618)	67,625 (65,243 to 69,419)	50,156	59,409	7.3	19.8	17.6	44.7
Low-middle SDI	17,563 (16,826 to 18,529)	25,876 (24,799 to 26,806)	20,482	22,559	16.6	11.8	18.9	47.3
Low SDI	5,162 (4,837 to 5,561)	7,308 (6,413 to 8,127)	6,829	6,865	32.3	0.7	8.6	41.6

SDI, sociodemographic index.