BMC Nephrology

RESEARCH

Open Access

Global forecasting of chronic kidney disease mortality rates and numbers with the generalized additive model

Fatemeh Shahbazi[1,2], Amin Doosti-Irani[1,3], Alireza Soltanian[4,5] and Jalal Poorolajal[1,5*]

Abstract

Background Chronic kidney disease (CKD) is an important public health problem worldwide; therefore, forecasting CKD mortality rates and death numbers globally is vital for planning CKD prevention programs. This study aimed to characterize the temporal trends in CKD mortality at the international level from 1990 to 2019 and predict CKD mortality rates and numbers until 2030.

Methods Data were obtained from the Global Burden of Disease 2019 Study. A joinpoint regression model was used to estimate the average annual percentage change in CKD mortality rates and numbers. Finally, we used a generalized additive model to predict CKD mortality through 2030.

Results The number of CKD-related deaths worldwide increased from 591.80 thousand in 1990 to 1425.67 thousand in 2019. The CKD age-adjusted mortality rate increased from 15.95 per 100,000 people to 18.35 per 100,000 people during the same period. Between 2020 and 2030, the number of CKD deaths is forecasted to increase further to 1812.85 thousand by 2030. The CKD age-adjusted mortality rate is expected to decrease slightly to 17.76 per 100,000 people (95% credible interval (CrI): 13.84 to 21.68). Globally, it is predicted that in the next decade, the CKD mortality rate will decrease in men, women, all subgroups of disease etiology except glomerulonephritis, people younger than 40 years old, and all groupings of countries based on the sociodemographic index (SDI) except high-middle-SDI countries.

Conclusions The CKD mortality rate is predicted to decrease in the next decade. However, more attention should be given to people with glomerulonephritis, people over 40 years old, and people in high- to middle-income countries because the mortality rate due to CKD in these subgroups is expected to increase until 2030.

Keywords Chronic kidney disease, Mortality, Prediction, Temporal trend, Modeling study

*Correspondence:
Jalal Poorolajal
poorolajal@umsha.ac.ir
[1]Department of Epidemiology, School of Public Health, Hamadan University of Medical Sciences, Hamadan, Iran
[2]Occupational Health and Safety Research Center, Health Science & Technology Research Institute, Hamadan University of Medical Sciences, Hamadan, Iran
[3]Research Center for Health Sciences, Health Science & Technology Research Institute, Hamadan University of Medical Sciences, Hamadan, Iran
[4]Department of Biostatistics, School of Public Health, Hamadan University of Medical Sciences, Hamadan, Iran
[5]Modeling of Non-Communicable Disease Research Center, Hamadan University of Medical Sciences, Hamadan, Iran

Background

Chronic kidney disease (CKD) is a public health problem [1] and refers to the irreversible failure of kidney function [2]. In this disease, the glomerular filtration rate can reach less than 60 ml/minute per 1.73 square meters for at least three months, or high albuminuria can occur [3]. This condition exposes CKD patients to complications, including hypertension, diabetes, dyslipidemia, cardiovascular disease, anemia, bone and mineral disorders, and weakening of the immune system [3–10]. On the other hand, the most important risk factors for CKD are type 2 diabetes mellitus, hypertension, and obesity, and due to changes in people's lifestyles, the prevalence of these risk factors and the subsequent prevalence of CKD are increasing [11, 12]. According to the most recent systematic analysis of the global burden of disease in 2017, 1.2 million people worldwide died from CKD [1]. According to this global study, between 1990 and 2017, the global all-age mortality rate from CKD increased by 41.5% [13].

Despite the sharp and transparent information about risk factors, complications, incidence and mortality rates from this health outcome, there is no research predicting the mortality rate of CKD in the future. Therefore, predicting the extent of this disorder in the future will help health system planners and policymakers deal with its complications and provide a general outline of what resources and to what extent are needed for better control of this disease [14]. In other words, using predictive models determines the speed of death due to health consequences in the future so that we can be better prepared to address them [15]. Finally, predicting future mortality rates by geographical area provides the basis for reducing inequalities because it determines which regions will suffer more from the CKD mortality in the future and requires more attention from health policymakers [16].

To address this issue, we used a generalized additive model (GAM) on CKD mortality at the global and national levels between 1990 and 2019 to forecast the future number of CKD deaths and mortality rates through 2030. Our predictions are essential for the reallocation of limited medical resources and for updating prevention strategies for CKD.

Methods

Data source

Chronic kidney disease data: In this ecological study, the researchers extracted the data related to the numbers and age-adjusted mortality rates from CKD between 1990 and 2019 by age, sex, country, etiology (type 1 diabetes mellitus, type 2 diabetes mellitus, hypertension, glomerulonephritis, and other cause), and grouping countries based on the sociodemographic index from the Global Burden of Disease result tools that is openly available at https://vizhub.healthdata.org/gbd-results/ [17]. We should mention that sociodemographic index (SDI) is a composite indicator of per capita income, educational attainment, and fertility rates. The value of this index is between zero and one. As long as SDI is close to one, it means that a country has a more favorable social and economic situation. GBD categorizes 204 countries worldwide into five groups based on their SDI levels, including low SDI, low-middle SDI, middle SDI, high-middle SDI, or high SDI.

Population data: We also extracted the corresponding population data by sex, year, age groups, and country from the United Nations Department of Economic and Social Affairs Population Division (https://population.un.org/wpp/Download/Standard/Population/) [18].

Model comparison and model selection

In epidemiological studies with the purpose of prediction, it is customary to compare several prediction models with each other in order to select the best model with the least error for prediction. These models in our study included a Bayesian age-period-cohort (BAPC) model, a generalized additive model (GAM), a smooth spline model, a joinpoint regression model, and a Poisson regression. For choosing the best model we first divided the global mortality data into two sets: a training set (1990–2013) and a testing set (2014–2019). Second, the global CKD mortality rates and case numbers between 2014 and 2019 were forecasted and compared with the actual values in the same period by the five mentioned models. Finally, we calculated the absolute percentage deviation (APD) and mean squared error (MSE) for each model to assess model accuracy via the following formulas:

- APD formula = $\sum [|\widehat{Y} - Y|/Y]*100$. Where, $\widehat{Y}$ is the predicted values and Y is the actual values between 2014 and 2019. The lower APD values indicating a better fit.
- MSE formula = $[(1/n)\sum_{i=1}^{n}(Yi - \widehat{Yi})^2]$. Where, Yi is the actual value of global CKD Mortality rates and $\widehat{Y}i$ is the predicted value by the each model. The smaller the MSE, the closer the models' predictions are to reality.

The APDs and MSEs was calculated for each model and is shown in Fig. 1. As shown in this figure, the values predicted using the generalized additive model had the most minor deviation compared to the actual values, so we used the GAM to predict CKD age-adjusted mortality rates and death numbers through 2030. The advantage of the GAM that leads to a better fit than the other four models is: (1) this model can be generalized to all types of response variables, (2) GAMs can model all types of relationships including linear, non-linear and complex

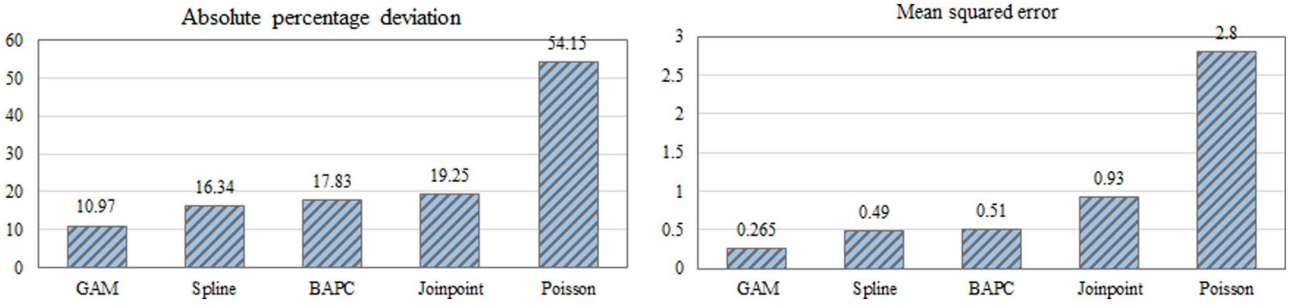

Fig. 1 The results of the model comparison based on the absolute percentage deviation (APD) and mean squared error (MSE) indices (based on this graph, when we predicted the testing set at the global level using the training set, the generalized additive model (GAM) had the least APD and MSE compared to the other four models)

patterns, (3) for forecasting purposes, GAM performs better than linear models, (4) due to additivity function, it can interpret the contribution of each predictor while holding other predictors constant, and (5) the GAMs can synthesize regularization techniques to avoid over fitting the model and improve generalization [19, 20].

Statistical analysis

Generalized additive model were used to predict the CKD numbers and age-adjusted rates until 2030. The GAM is written as follows:

$$\ln(numbers) = s[\ln(pnum)] + s(c) + s(year) + s(e) + r$$

Were numbers refers to the count of CKD death, pnum is the population; c denotes the median age in each age group; year represents the calendar year; and e is the calendar year minus mid value of age group; r is the intercept; and the s is a smoothing spline function. The smoothness of each function determined by the smoothing regularization parameter known λ. In our study λ was varies from 0.10 to 0.90. We obtained the predicted values until 2030 and corresponding 95% credible interval (CrI) using bootstrap method. We should mention that choosing 2030 as the end point of the forecasts is linked to the Sustainable Development Goals. This goals adopted in September 2015 by the heads of state and high-level representatives of the specialized agencies of the United Nations and civil society, adopted by the General Assembly of the United Nations and setting the goal to achieve this by 2030. The main goal of this document is to address poverty in all its forms worldwide; consequently, most public health and medical studies have set the endpoint of their predictions for 2030.

All statistical analyses were performed using R version 4.1.2 (R Foundation for Statistical Company, Vienna, Austria). It should be noted that the GAM was implemented with a package with the same name in R software.

Quantifying the CKD mortality trends

After the CKD age-adjusted mortality rates were predicted until 2030 using GAM, we describe temporal trends of mortality rates using the average annual percent changes (AAPC). This quantitative measure evaluate the average annual variation in mortality rates during a specific period (in our study included 1990–2019 and 2020–2030). The positive and negative values of this measure indicates an increasing or decreasing trend in the mortality rate during the study period, respectively. In calculation AAPC, the natural logarithm of time variables fitted against their corresponding mortality rates. In other words, we established a relationship between the natural logarithm (ln) of the age-adjusted mortality rates and time using the following equation: $y=b_0+\beta x+\epsilon$. In this equation, y indicates ln (age-adjusted mortality rates), x indicates the calendar year, b_0 is intercept, ϵ is error term, and β is the direction (positive or negative) of the trend in the chosen of the trend in the chosen age-adjusted mortality rate. Then, we calculated the AAPC using the (exponential [β]-1) *100 formula.

Results

Chronic kidney disease death numbers and age-adjusted mortality rates, 1990–2019

Globally, the number of CKD deaths increased from 591.80 thousand in 1990 to 1425.67 thousand in 2019. The CKD age-adjusted mortality rate increased from 15.95 per 100,000 to 18.35 per 100,000 during the same period (AAPC=0.5, 95% confidence interval (CI): 0.4 to 0.6). This means that on average, we are seeing a 0.5% annual increase in the age-adjusted mortality rate from CKD (Table 1; Figs. 2 and 3). Both sexes experienced increasing trends in the number of deaths and age-adjusted mortality rate. During the study period, the number of CKD deaths in men increased more than two-fold (from 309.53 thousand in 1990 to 741.03 thousand in 2019). Additionally, among women, the number of deaths increased from 282.27 thousand in 1990 to 684.64 thousand in 2019. During this period, the age-adjusted

Table 1 The number of deaths and age-adjusted mortality rate of CKD patients in 1990 and 2019 stratified by sex, etiology, age group, and country group based on the SDI

	Death numbers (×1000)		Age adjusted mortality rate (×100,000)		AAPC [a] (95% CI) of ASR
	1990	2019	1990 (95% CI)	2019 (95% CI)	1990–2019
Sex					
Both	591.80	1425.67	15.95 (15.84, 16.06)	18.35 (18.24, 18.46)	0.5 (0.4, 0.6)
Male	309.53	741.03	19.35 (19.22, 19.49)	21.69 (21.55, 21.82)	0.4 (0.3, 0.5)
Female	282.27	684.64	13.71 (13.61, 13.81)	15.84 (15.74, 15.94)	0.5 (0.4, 0.6)
Etiology					
Diabetes mellitus I	42.54	81.77	0.95 (0.94, 0.96)	0.98 (0.97, 0.99)	0.1 (0.0, 0.2)
Diabetes mellitus II	146.02	406.29	4.09 (4.05, 4.12)	5.19 (5.15, 5.22)	0.8 (0.7, 0.9)
Hypertension	169.11	447.69	5.03 (5.00, 5.07)	5.87 (5.84, 5.91)	0.5 (0.4, 0.6)
Glomerulonephritis	90.96	182.84	2.20 (2.18, 2.21)	2.31 (2.30, 2.33)	0.2 (0.1, 0.3)
Other causes	143.16	307.08	3.68 (3.65, 3.72)	3.99 (3.96, 4.03)	0.3 (0.2, 0.4)
Age groups (year)[b]					
0–19	36.04	26.16	1.58 (1.57, 1.59)	1.01 (1.00, 1.02)	-1.5 (-1.6, -1.4)
20–39	55.95	74.20	13.94 (13.74, 14.13)	12.82 (12.63, 13.02)	-0.3 (-0.4, -0.2)
40–59	126.04	258.80	59.12 (58.56, 59.67)	61.57 (61.02, 62.13)	0.1 (0.0, 0.2)
≥ 60	373.77	1066.51	213.13 (211.46, 214.80)	269.77 (268.10, 271.43)	0.8 (0.7, 0.9)
Sociodemographic index (SDI)					
Low SDI	61.88	124.65	27.21 (27.08, 27.34)	25.26 (25.13, 25.39)	-0.3 (-0.4, -0.2)
Low-middle SDI	124.78	292.88	21.75 (21.47, 22.04)	22.97 (22.68, 23.25)	0.2 (0.1, 0.3)
Middle SDI	193.53	505.64	20.83 (20.68, 20.97)	22.94 (22.79, 23.10)	0.3 (0.2, 0.4)
High-middle SDI	114.69	226.36	12.10 (11.98, 12.22)	11.71 (11.59, 11.83)	-0.1 (-0.2, 0.0)
High SDI	96.54	275.18	9.40 (9.26, 9.52)	12.69 (12.56, 12.82)	1.1 (1.0, 1.2)

[a] Average annual percent change (AAPC): The 95% CIs of the AAPC were calculated by using the joinpoint regression model

[b] The mortality rates for age groups were not adjusted for age

mortality rates in men and women increased from 19.35 to 21.69 per 100,000 people (AAPC=0.4, 95% CI: 0.3 to 0.5) and from 13.71 to 15.84 per 100,000 people (AAPC=0.5, 95% CI: 0.4 to 0.6), respectively. On the other hand, the number of deaths and age-adjusted mortality rate were greater in women than in men between 1990 and 2019. The number of deaths in all age groups increased between 1990 and 2019, except for the age group younger than 19 years (Table 1; Fig. 3). Among all age subgroups, the greatest increase in the number of CKD deaths was related to the age group older than 60 years (the number of deaths in 2019 was almost three times that in 1990). Among CKD etiological factors, hypertension and type 2 diabetes mellitus had the highest number of deaths and age-adjusted mortality rates, respectively. The number of CKD deaths with origin of hypertension increased from 169.11 thousand in 1990 to 447.69 thousand in 2019. Additionally, the number of CKD deaths caused by type 2 diabetes mellitus increased from 146.02 thousand in 1990 to 406.29 thousand in 2019. The CKD age-adjusted mortality rate due to hypertension increased from 5.03 per 100,000 people in 1990 to 5.87 per 100,000 people in 2019. Additionally, from 1990 to 2019, the age-adjusted mortality rate of CKD caused by type 2 diabetes mellitus increased from 4.09 to 5.19 per 100,000 people. When nations were grouped based on the sociodemographic index (SDI), the highest CKD age-adjusted mortality rate was observed in the low-SDI countries. In these areas, the CKD age-adjusted mortality rate decreased from 27.21 per 100,000 people in 1990 to 25.26 per 100,000 people in 2019. More details about the number of deaths and age-adjusted mortality rates for countries grouped based on the SDI are presented in Table 1.

Chronic kidney disease death numbers and age-adjusted mortality rates, 2020–2030

Between 2020 and 2030, the number of CKD deaths increased from 1461.11 thousand to 1812.85 thousand (Table 2; Fig. 3). It is forecasted that in the next decade, the CKD age-adjusted mortality rate will decrease from 18.30 per 100,000 people in 2020 to 17.76 per 100,000 people in 2030 (AAPC = -0.3, 95% credible interval (CrI): -0.4 to -0.2) (Table 2; Fig. 2). This decreasing trend in the CKD age-adjusted mortality rate is also predicted for both sexes until 2030. Men and women will experience 0.3% and 0.2% reductions in the CKD age-adjusted mortality rate each year over the next decade, respectively. The number of CKD deaths will increase to 935.60 thousand in males and 874.12 thousand in females between 2020 and 2030. Contrary to the increasing trend in CKD-related death numbers, the CKD age-adjusted mortality

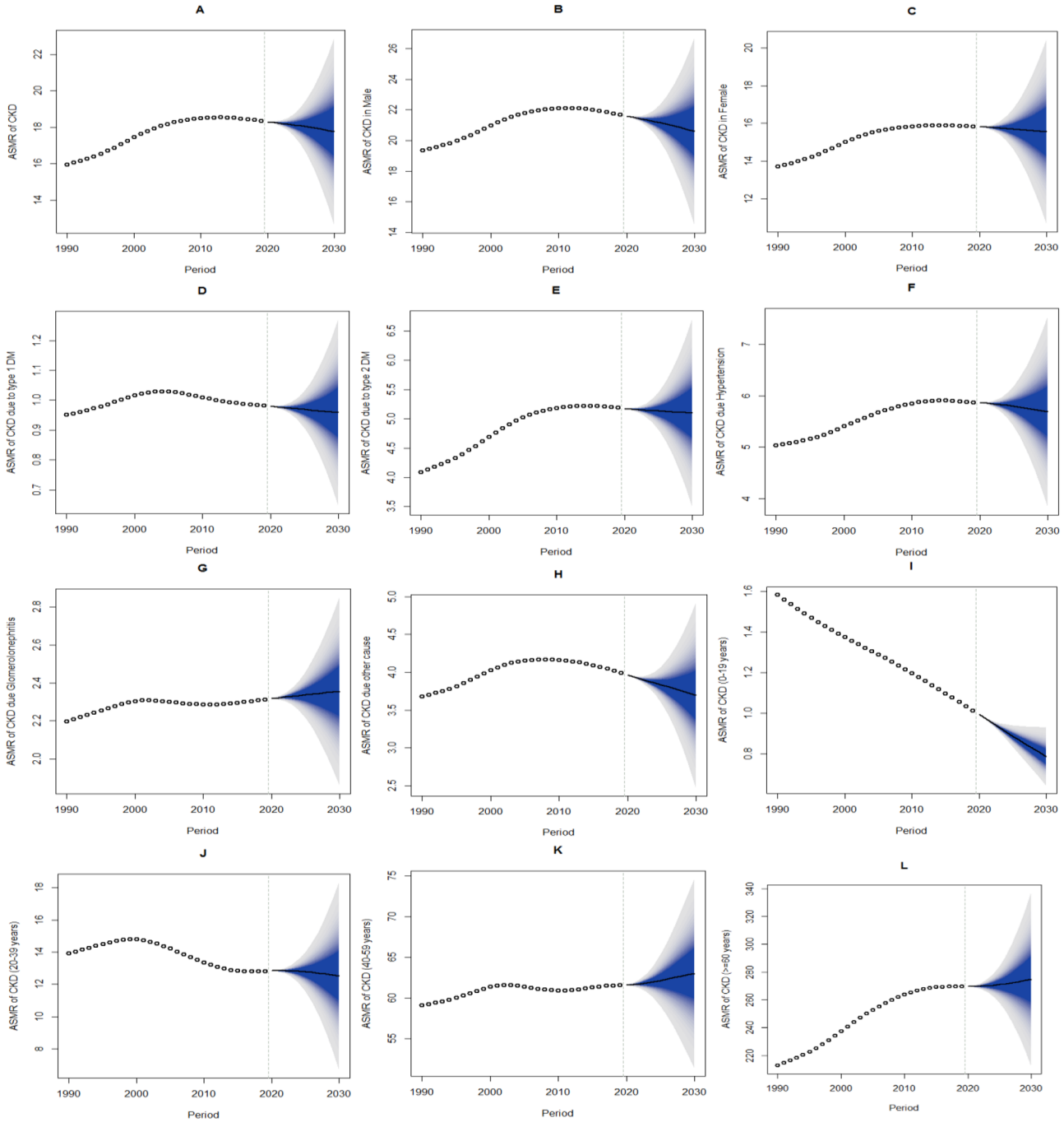

Fig. 2 (**A**–**L**) The temporal trends of age-specific mortality rates (per 100,000) of CKD between 1990 and 2019 and their projections up to 2030 at the global level (**A**: both sexes, **B**: male, **C**: female, **D**: DM type 1, **E**: DM type 2, **F**: hypertension, **G**: glomerulonephritis, **H**: other cause, **I**: 0–19 years, **J**: 20–39 years, **K**: 40–59 years, **L**: ≥60 years). The incidence rates for the four age groups are crude and not age-adjusted. The open dots represent the observed values, and the fan shape denotes the predictive distribution between the 2.5 and 97.5% quintiles. The predictive mean value is shown as a solid line. The vertical dashed line indicates where the prediction starts

rate will decrease to 20.60 per 100,000 in men (95% CrI: 15.93 to 25.27) and 15.56 per 100,000 in women (95% CrI: 11.83 to 19.30) until 2030 (Table 2; Fig. 2). The number of deaths is predicted to increase for all etiological groups of CKD patients. CKD age-adjusted mortality rates are predicted to decrease for all etiological subgroups and different countries categorized based on the SDI, except for CKD due to glomerulonephritis (Table 2; Fig. 2). It is forecasted that the CKD mortality rates in populations younger than 19 years, 20–39 years, 40–59 years, and older than 60 years in 2030 will be 0.79, 12.52, 63.00, and 274.87 per 100,000 people, respectively.

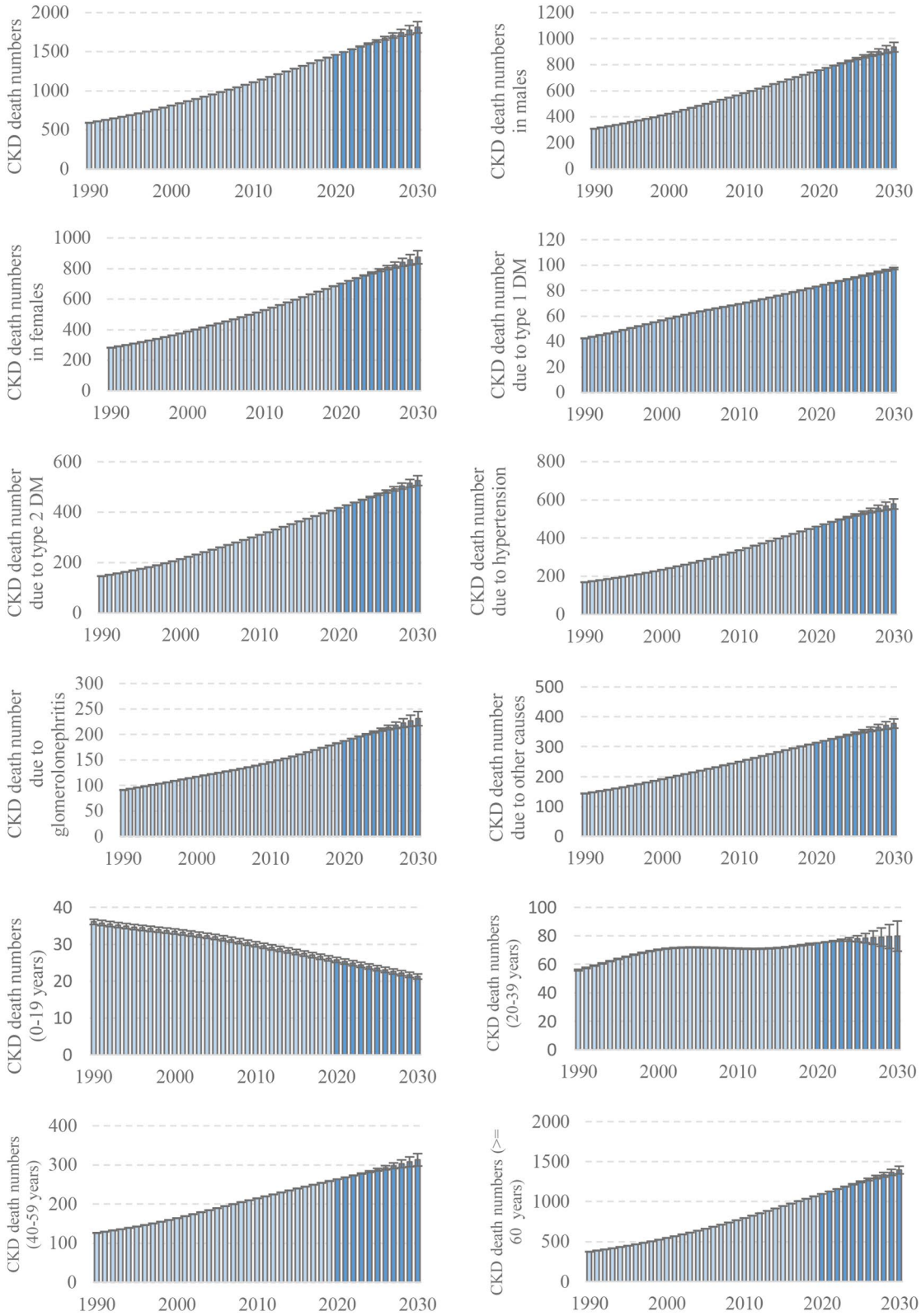

Fig. 3 The trends in the number of deaths from chronic kidney disease between 1990 and 2030 at the global level according to sex and etiology. The error bars denote the 95% confidence intervals of the prediction values. The y-axes are on a scale of thousands

Table 2 The number of deaths predicted and age-adjusted mortality rate of CKD patients in 2020 and 2030 stratified by sex, etiology, age group, and country group based on the SDI

	Death numbers (×1000)		Age adjusted mortality rate (×100,000)		AAPC [a] (95% CrI) of ASR
	2020	2030	2020 (95% CrI)	2030 (95% CrI)	2020–2030
Sex					
Both	1461.11	1812.85	18.30 (18.29, 18.31)	17.76 (13.84, 21.68)	-0.3 (-0.4, -0.2)
Male	758.75	935.60	21.60 (21.58, 21.61)	20.60 (15.93, 25.27)	-0.3 (-0.4, -0.2)
Female	702.33	874.12	15.82 (15.81, 15.83)	15.56 (11.83, 19.30)	-0.2 (-03, -0.1)
Etiology					
Diabetes mellitus I	83.21	97.40	0.97 (0.96, 0.98)	0.96 (0.72, 1.20)	-0.2 (-03, -0.1)
Diabetes mellitus II	417.00	525.35	5.18 (5.17, 5.19)	5.10 (3.87, 6.33)	-0.2 (-03, -0.1)
Hypertension	460.26	578.67	5.86 (5.85, 5.87)	5.69 (4.28, 7.10)	-0.3 (-0.4, -0.2)
Glomerulonephritis	187.29	231.12	2.32 (2.31, 2.33)	2.36 (1.98, 2.74)	0.2 (0.1, 0.3)
Other causes	313.32	377.30	3.96 (3.95, 3.97)	3.70 (2.76, 4.63)	-0.7 (-0.8, -0.6)
Age groups (year)[b]					
0–19	25.73	21.24	0.99 (0.98, 1.00)	0.79 (0.68, 0.90)	-2.3 (-2.4, -2.2)
20–39	74.96	79.82	12.84 (12.83, 12.85)	12.52 (8.07, 16.97)	-0.2 (-0.3, -0.1)
40–59	263.50	313.01	61.61 (61.58, 61.65)	63.00 (54.13, 71.88)	0.2 (0.1, 0.3)
≥ 60	1096.91	1395.32	269.77 (269.65, 269.89)	274.87 (227.08, 322.65)	0.2 (0.1, 0.3)
Sociodemographic index (SDI)					
Low SDI	127.75	157.65	25.14 (25.13, 25.16)	23.92 (18.49, 39.35)	-0.5 (-0.6, -0.4)
Low-middle SDI	300.61	377.88	22.93 (22.91, 22.94)	22.57 (17.54, 27.59)	-0.2 (-03, -0.1)
Middle SDI	519.07	651.49	22.85 (22.84, 22.86)	21.65 (17.10, 26.19)	-0.5 (-0.6, -0.4)
High-middle SDI	231.17	276.21	12.48 (11.71, 13.25)	12.48 (11.71, 13.25)	0.0 (0.0, 0.0)
High SDI	231.17	340.92	12.67 (12.66, 12.68)	12.36 (9.79, 14.93)	-0.2 (-03, -0.1)

[a] Average annual percent change (AAPC): The 95% CrIs of the AAPC were calculated by using the joinpoint regression model

[b] The mortality rates for age groups were not adjusted for age

In the countries of Central America, the United States, Mexico, Venezuela, Ecuador, Kazakhstan, Norway, Sweden, Finland, Belarus, Ukraine, and Germany the trends of CKD mortality rates will increase by 2030 with a steeper slope than other countries where the trend of CKD is increasing (Fig. 4). On the other hand, the CKD mortality rates in Colombia and Brazil in Central America, most African countries, Russia, Mongolia, China, Iran, India and other countries marked with green color in Fig. 4-C will decrease by 2030.

Discussion

In the present study, we explored the temporal trends in CKD mortality rates globally from 1990 to 2019. Additionally, we predict CKD age-adjusted mortality rates and numbers until 2030. Our analysis revealed that the CKD deaths number have increased significantly over the past thirty years (1990 to 2019). This increasing trends in CKD death numbers was observed in both sexes, all disease subgroups by etiology, all groupings of countries based on the sociodemographic index, and all age subgroups (except for people younger than 19 years). From 1990 to 2019, the global age-standardized mortality rate due to CKD had two situations, a rapid increase between 1990 and 2010, and a flat or decreasing trend following 2010 (except for the age group younger than 19 years). It is expected that the CKD age-adjusted mortality rate will decrease by 2030, which is the opposite of the trends observed in the last thirty years. This decreasing trend was observed in women, men, all grouping countries based on the SDI, all etiological groups of CKD except glomerulonephritis, and people younger than 39 years.

The findings of this study revealed that people older than 60 years in the world have the highest age-adjusted mortality rate due to CKD compared to the other age groups. In justification this issue, we must say with increasing the age, we usually observe a decrease in the amount of glomerular filtration and albuminuria (excessive leakage of protein in the urine, which indicates kidney disease). The last two events increase the risk of adverse outcomes, including chronic kidney disease, cardiovascular disease, and all-cause mortality, in elderly individuals [21]. On the other hand, the world population is aging. Currently, there are 420 million older adults over 65 years in the world, and this number is expected to reach 1.5 billion in 2050. This shows that the number of older people is increasing in developed and developing countries [22]. These older people have many comorbidities; for example, more than 30% of them are obese, almost 11% have diabetes, and 33% have high blood pressure [23]. These outcomes are among the well-known risk factors of CKD, and their comorbidity with old age and

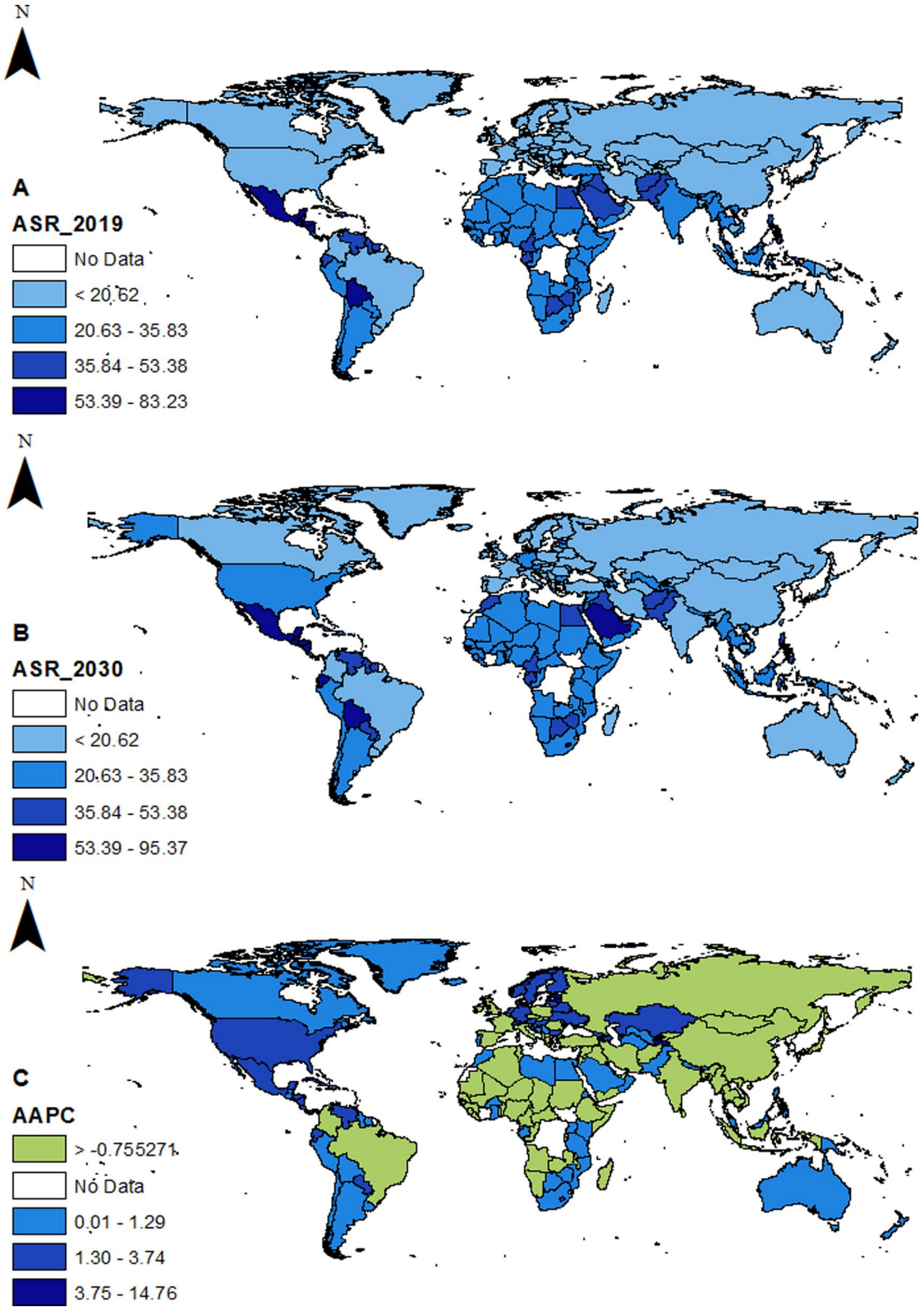

Fig. 4 The global distribution and average annual percentage changes (AAPCs) in age-adjusted mortality rates (ASMRs per 100,000) of chronic kidney disease at the global level. (**A**) ASMR of chronic kidney disease in 2019; (**B**) ASMR of chronic kidney disease in 2030; (**C**) AAPC of chronic kidney disease ASMR between 1990 and 2030

their increasing trend provide the basis for the occurrence and mortality from CKD in older adults. Epidemiological evidence also shows that the high incidence of cardiovascular diseases in the elderly is one of the underlying factors for chronic kidney disease. This is because these two health outcomes are associated with common risk factors, such as obesity, hypertension, and diabetes mellitus [22].

Type 2 diabetes mellitus is the second leading cause of death in patients with chronic kidney disease. Anemia is a common complication that severely affects the clinical outcomes of people with diabetes. Many observational studies have shown that low hemoglobin levels increase the risk of developing chronic kidney disease caused by diabetes mellitus, cardiovascular complications, and death [24].

According to the findings of the present study, the mortality rate from chronic kidney disease is greater in men than in women. In contrast, according to previous studies, the incidence rate in women is greater than that in men [25]. The global sex difference in the CKD mortality rate is likely the result of a complex combination of sex and social factors, including unequal access to medical care, kidney replacement therapy, and disease-stopping therapy [25–27]. Additionally, according to a meta-analysis of 30 observational studies, the progression of chronic kidney disease in men is faster than that in women. Men reach the final stages of CKD and its adverse consequences, including dialysis, kidney transplantation and death, faster than women due to prolonging reasons [28]. According to animal models, male animals experience more severe kidney damage than their female counterparts. This causes a faster progression of the disease and more and faster death in male animals with chronic kidney disease than in females [29, 30]. Additionally, based on numerous studies, men with CKD start dialysis later than women, and compared to them, women pay more attention to various aspects of their health. Women use more medical care and diagnostic tests than men, so the possibility of early diagnosis of various health outcomes, including CKD, is greater for women than men. Therefore, CKD is mainly diagnosed in men in the final stages, where the mortality rate is higher [28, 31]. On the other hand, according to the study conducted by Katran et al., renal survival in women with glomerulosclerosis was greater than that in men, which explains the greater rate of death due to chronic kidney disease in men than in women [32].

In terms of the mortality trends, our analysis indicated that the mortality rate due to chronic kidney disease decreased worldwide and decreased in people under 40 years old, both sexes, all grouping countries based on the SDI, and all etiological subgroups (except for the glomerulonephritis). To justify this decreasing trend, we can point out the expansion of the use of angiotensin-converting enzyme inhibitors and angiotensin receptor blockers in the treatment chronic kidney disease [33]. In addition to proper effectiveness, these medications have advantages such as good tolerance and limited side effects. The use of these interventions delays the onset of the final stage of CKD and surgical kidney transplantation, improves the survival time of chronic kidney patients, and finally reduce the mortality from CKD. On the other hand, the existence of common risk factors makes cardiovascular diseases prevalent in all stages of chronic kidney disease. In recent years, expanding the use of coronary artery bypass surgery and increase the use of percutaneous coronary interventions has led to the control of cardiovascular complications in CKD patients and a reduction in the mortality rate caused by heart diseases in these patients [34, 35]. These interventions lead to the control of angina symptoms in patients with chronic coronary diseases and increased survival time in patients with acute coronary syndromes, and in people who suffer from cardiovascular diseases and chronic kidney diseases, these interventions reduce the number of deaths due to heart complications [36]. Expanding the use of angiotensin-converting enzyme inhibitors and angiotensin receptor blockers will lead to the control of blood pressure, blood sugar, and the reduction of albumin excretion through urine, thereby reducing the mortality rate in chronic kidney diseases caused by hypertension and diabetes mellitus [37]. Additionally, the use of warfarin and aspirin at regulated doses will lead to a reduction in stroke, systemic embolism, and atrial fibrillation, and following these cases, we will see a reduction in the mortality rate due to heart complications in CKD patients [38, 39]. The use of vitamin K antagonists or new oral anticoagulants in patients with atrial fibrillation will reduce the mortality rate due to cardiac complications caused by chronic kidney disease [40]. Additionally, the results of a systematic review and meta-analysis showed that the use of statins leads to a reduction in all-cause mortality as well as cardiovascular disease mortality in CKD patients [41]. Since 1990, the use of high-flux and high-quality filters has steadily increased. According to a survey conducted by the Centers for Disease Control in 1994, high-flux filters were used by 45% and high-quality filters by 51% of CKD patients. The list of high-flux and high-quality treatments for chronic kidney disease patients includes high-quality hemodialysis, high-flux hemodialysis, intermittent hemofiltration, and intermittent hemodiafiltration. Expanding the use of the aforementioned methods increased the ability of dialysis centers to remove medium-weight toxic molecules in CKD patients. In other words, in the final stages of chronic kidney disease, the amount of glomerular filtration reaches less than 15 milliliters per minute,

and the accumulation of toxins causes uremic syndrome. This syndrome can lead to death. These deadly toxins must be removed from the body using one of the three methods of hemodialysis, peritoneal dialysis or kidney transplant. Membranes or low flux filters that contain small pores are unable to remove medium molecules due to their small pores. In contrast, the use of filters or high-flux membranes has more power in the clearance and purification of urea. Therefore, the increase in the use of high-flux filters or membranes leads to the improvement of the quality of dialysis, the improvement of the quality of life in patients with chronic kidney disease, the reduction of hospitalization in medical centers, the reduction of treatment costs and, ultimately, the reduction of the mortality rate due to CKD in the next decade [42–44].

According to a study conducted by Shahbazi et al. in 2023, the CKD incidence rate will increase worldwide and in the next decade [25], while based on the results of the present study, we will see a decreasing trend in the CKD mortality rate in the next decade worldwide. This finding may be surprising at first because we would expect to see a proportional increase in mortality rates as the incidence rate increases. To justify this finding, we can mention the expansion of access to diagnostic services and the improvement of patient survival. In other words, the increase in medical examinations in recent years justifies the increasing trend in the incidence of CKD because mild and moderate cases of this disease have also been detected. The identification of milder cases of CKD that are in the early stages of disease allows more effective, less expensive, and less invasive treatments to be offered to these patients, and subsequently, the mortality rate due to CKD will decrease [45].

Our analysis revealed that the CKD mortality rate was greater in low-SDI countries than in high-SDI countries. This finding can be attributed to deprived countries having less access to timely diagnostic services and subsequently less access to new and more effective treatment methods [46].

This study has some limitations. First, the present research is an ecological study, which by its nature prevents causal inference due to aggregate data. In this context, the level of data coverage and reporting of each region can affect the results of trends and forecasts. Second, as with all prediction models, our model cannot forecast unexpected fluctuations or major changes in trend. Third, in the present study, we used data from the global burden of disease website for modeling. These data were estimated from mathematical models based on surveillance data rather than surveillance data. Therefore, all these issues should be considered in the interpretation of the results.

Conclusions

In summary, CKD mortality is predicted to decrease in the next decade. The most pronounced decrease is expected among people with hypertension, people with diabetes mellitus, and younger people, suggesting that current prevention strategies should focus on subgroups that still have an increasing trend until 2030. Effective preventive measures are still needed to reduce death from CKD in people with glomerulonephritis and people older than 40 years.

Abbreviations

GAM	Generalized additive model
CKD	Chronic kidney disease
CrI	Credible interval
SDI	Sociodemographic index
BAPC	Bayesian age-period-cohort
APD	Absolute percentage deviation
AAPC	Average annual percentage change

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12882-024-03720-w.

Supplementary Material 1

Acknowledgements

This study was part of a Ph.D. thesis in Epidemiology. We highly appreciate the global burden of disease websites, which have made data available for researchers around the world to conduct global, regional, and national research.

Author contributions

Conceptualization: Shahbazi F, Doosti-Irani A, Soltanian A, Poorolajal J. Data curation: Shahbazi F. Formal analysis: Shahbazi F, Soltanian A. Funding acquisition: Poorolajal J. Methodology: Shahbazi F, Doosti-Irani A, Soltanian A, Poorolajal J. Project administration: Shahbazi F, Poorolajal J. Visualization: Shahbazi F, Doosti-Irani A, Soltanian A, Poorolajal J. Writing – original draft: Shahbazi F, Doosti-Irani A, Soltanian A, Poorolajal J. Writing – review & editing: Shahbazi F, Poorolajal J.

Funding

This study was approved without receiving any funding from the Modeling of Noncommunicable Diseases Research Center of Hamedan University of Medical Sciences (grant number 140009308068).

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 1 March 2024 / Accepted: 20 August 2024
Published online: 02 September 2024

References

1. Carney EF. The impact of chronic kidney disease on global health. Nat Rev Nephrol. 2020;16(5):251–2.
2. Yan M-T, Chao C-T, Lin S-H. Chronic kidney disease: strategies to retard progression. Int J Mol Sci. 2021;22(18):10084.
3. Almaawi AKM. Detecting chronic kidney disease in diabetic adults by estimating glomerular filtration rate and serum creatinine. J Contemp Med Sci. 2021;7(1).
4. Bhatt DL, Szarek M, Pitt B, Cannon CP, Leiter LA, McGuire DK, et al. Sotagliflozin in patients with diabetes and chronic kidney disease. N Engl J Med. 2021;384(2):129–39.
5. Weldegiorgis M, Woodward M. The impact of hypertension on chronic kidney disease and end-stage renal disease is greater in men than women: a systematic review and meta-analysis. BMC Nephrol. 2020;21(1):1–9.
6. Wheeler DC, Stefánsson BV, Jongs N, Chertow GM, Greene T, Hou FF, et al. Effects of dapagliflozin on major adverse kidney and cardiovascular events in patients with diabetic and non-diabetic chronic kidney disease: a prespecified analysis from the DAPA-CKD trial. Lancet Diabetes Endocrinol. 2021;9(1):22–31.
7. Espi M, Koppe L, Fouque D, Thaunat O. Chronic kidney disease-associated immune dysfunctions: impact of protein-bound uremic retention solutes on immune cells. Toxins. 2020;12(5):300.
8. Hazin MAA. Anemia in chronic kidney disease. Revista Da Associação Médica Brasileira. 2020;66:s55–8.
9. Jankowski J, Floege J, Fliser D, Böhm M, Marx N. Cardiovascular disease in chronic kidney disease: pathophysiological insights and therapeutic options. Circulation. 2021;143(11):1157–72.
10. Thobani A, Jacobson TA. Dyslipidemia in patients with kidney disease. Cardiol Clin. 2021;39(3):353–63.
11. Jitraknatee J, Ruengorn C, Nochaiwong S. Prevalence and risk factors of chronic kidney disease among type 2 diabetes patients: a cross-sectional study in primary care practice. Sci Rep. 2020;10(1):6205.
12. Wang C-P, Lu Y-C, Hung W-C, Tsai I-T, Chang Y-H, Hu D-W, et al. Inter-relationship of risk factors and pathways associated with chronic kidney disease in patients with type 2 diabetes mellitus: a structural equation modelling analysis. Public Health. 2021;190:135–44.
13. Chen A, Zou M, Young CA, Zhu W, Chiu H-C, Jin G, et al. Disease burden of chronic kidney disease due to hypertension from 1990 to 2019: a global analysis. Front Med. 2021;8:690487.
14. Du Z, Chen W, Xia Q, Shi O, Chen Q. Trends and projections of kidney cancer incidence at the global and national levels, 1990–2030: a bayesian age-period-cohort modeling study. Biomark Res. 2020;8(1):1–10.
15. Siegel E. Predictive analytics: the power to predict who will click, buy, lie, or die. Wiley; 2013.
16. Luyckx VA, Al-Aly Z, Bello AK, Bellorin-Font E, Carlini RG, Fabian J, et al. Sustainable development goals relevant to kidney health: an update on progress. Nat Rev Nephrol. 2021;17(1):15–32.
17. Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2017 (GBD 2017) Results. Seattle: Institute for Health Metrics and Evaluation (IHME) 2023 [https://vizhub.healthdata.org/gbd-results/
18. United Nations (UN). Standard Projections (Estimates and Projection Variants): Population Data New York City 2022 2024 [https://population.un.org/wpp/download/standard/population/
19. Hastie T, Tibshirani R. Generalized additive models: some applications. J Am Stat Assoc. 1987;82(398):371–86.
20. Baayen RH, Linke M. An introduction to the generalized additive model. A practical handbook of corpus linguistics. 2020:563 – 91.
21. Lin M-Y, Chiu Y-W, Lee C-H, Yu H-Y, Chen H-C, Wu M-T, et al. Factors associated with CKD in the elderly and nonelderly population. Clin J Am Soc Nephrology: CJASN. 2013;8(1):33.
22. Stevens LA, Viswanathan G, Weiner DE. CKD and ESRD in the elderly: current prevalence, future projections, and clinical significance. Adv Chronic Kidney Dis. 2010;17(4):293.
23. Control CfD, on diabetes in the United States. Prevention. National diabetes fact sheet: general information and national estimates, 2007. Atlanta, GA: US Department of Health and Human Services, Centers for Disease Control and Prevention. 2008;1.
24. Mehdi U, Toto RD. Anemia, diabetes, and chronic kidney disease. Diabetes Care. 2009;32(7):1320–6.
25. Shahbazi F, Doosti-Irani A, Soltanian A, Poorolajal J. National trends and projection of chronic kidney disease incidence according to etiology from 1990 to 2030 in Iran: a bayesian age-period-cohort modeling study. Epidemiol Health. 2023:e2023027.
26. Hockham C, Schanschieff F, Woodward M. Sex differences in CKD-associated mortality from 1990 to 2019: data from the global burden of disease study. Kidney Med. 2022;4(10):100535.
27. García GG, Iyengar A, Kaze F, Kierans C, Padilla-Altamira C, Luyckx VA, editors. Sex and gender differences in chronic kidney disease and access to care around the globe. Seminars in nephrology. Elsevier; 2022.
28. Neugarten J, Golestaneh L, editors. Influence of sex on the progression of chronic kidney disease. Mayo Clinic Proceedings; 2019: Elsevier.
29. Baylis C, Corman B. The aging kidney: insights from experimental studies. J Am Soc Nephrol. 1998;9(4):699–709.
30. Silbiger SR, Neugarten J. The impact of gender on the progression of chronic renal disease. Am J Kidney Dis. 1995;25(4):515–33.
31. Ebrahimi S, Haghi F. Comparison of dialysis practice and medication prescription pattern in chronic kidney disease patients undergoing hemodialysis at tertiary care and private hospital, Pune, India. ACADEMIC JOURNAL.
32. Cattran DC, Reich HN, Beanlands HJ, Miller JA, Scholey JW, Troyanov S. The impact of sex in primary glomerulonephritis. Nephrol Dialysis Transplantation. 2008;23(7):2247–53.
33. Ferrari P. Prescribing angiotensin-converting enzyme inhibitors and angiotensin receptor blockers in chronic kidney disease. Nephrology. 2007;12(1):81–9.
34. Kim JY, Steingroever J, Lee KH, Oh J, Choi MJ, Lee J, et al. Clinical interventions and all-cause mortality of patients with chronic kidney disease: an umbrella systematic review of meta-analyses. J Clin Med. 2020;9(2):394.
35. Garcia Sanchez JJ, Thompson J, Scott DA, Evans R, Rao N, Sörstadius E, et al. Treatments for chronic kidney disease: a systematic literature review of randomized controlled trials. Adv Therapy. 2022;39(1):193–220.
36. Marx N, Floege J. Cardiovascular disease in patients with chronic kidney disease. Herz. 2021;46(3):205.
37. Mavridis D, Palmer SC, Strippoli GF. Comparative superiority of ACE inhibitors over angiotensin receptor blockers for people with CKD: does it matter? Am J Kidney Dis. 2016;67(5):713–5.
38. Hart RG, Pearce LA, Asinger RW, Herzog CA. Warfarin in atrial fibrillation patients with moderate chronic kidney disease. Clin J Am Soc Nephrology: CJASN. 2011;6(11):2599.
39. Hjerteavdelingen U. 2016 ESC guidelines for the management of atrial fibrillation developed in collaboration with EACTS. Eur Heart J. 2016;37(2893).
40. Cozzolino M, Mangano M, Galassi A, Ciceri P, Messa P, Nigwekar S. Vitamin K in chronic kidney disease. Nutrients. 2019;11(1):168.
41. Herrington W, Emberson J, Mihaylova B, Blackwell L, Reith C, Haynes R et al. Impact of renal function on the effects of LDL cholesterol lowering with statin-based regimens: a meta-analysis of individual participant data from 28 randomised trials. Lancet Diabetes Endocrinol. 2016;4(10).
42. Haghighi MJ, Shahdadi H, Abdollahimohammad A, Moghadam MP. The effect of low-flux and high-flux filters on adequacy and complications during hemodialysis of patients. Der Pharmacia Lettre. 2016;8(19):395–9.
43. Narimani R, Pour-Pouneh M, Mardani S, Kheiri S, Nasri H. Comparison of high-flux and low-flux hemodialysis filters on hemodialysis adequacy in under-hemodialysis patients with end-stage renal disease. J Isfahan Med School. 2015;33(331):563–73.
44. Noee MNG, Hasani J, Erfanpoor S, Jafari H. Relationship between the filter type and blood flow rate and, dialysis adequacy in hemodialysis patients. J Nurs Midwifery Sci. 2020;7(2):94.
45. Leon G. Occurrence of the disease: 2 mortality and other indicators of the impact of the disease. Epidemiology. 5th edition ed ed. Philadelphia: Saunders2014.
46. Feng X, Hou N, Chen Z, Liu J, Li X, Sun X, et al. Secular trends of epidemiologic patterns of chronic kidney disease over three decades: an updated analysis of the global burden of Disease Study 2019. BMJ open. 2023;13(3):e064540.

Publisher's note