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ARTICLE

Global Burden of Severe Heart Failure Attributable to Chronic Kidney Disease in Diabetes Populations: A Systematic Analysis of the Global Burden of Disease Study 2021

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Abstract

Aims/Background Severe heart failure (SHF) secondary to chronic kidney disease (CKD) in type 1/2 diabetes mellitus (T1/T2DM) patients presents a critical global health challenge. Leveraging data from the Global Burden of Disease (GBD) 2021, we analyse epidemiological trends (1990–2021) and project disease trajectories to 2040, focusing on sociodemographic disparities and metabolic determinants.

Methods Utilising GBD 2021 data, the estimated prevalence and years lived with disability (YLDs) values were extracted for SHF-CKD-T1/T2DM, along with their corresponding 95% uncertainty intervals (UIs). The trend in SHF-CKD-T1/T2DM burden between 1990 and 2021 was evaluated from both a global and local perspective. Subgroup analysis was employed to examine the burden of SHF-CKD-T1/T2DM across various subpopulations. Additionally, decomposition analysis was used to assess the contributions of population size, age structure, and epidemiological changes to SHF-CKD-T1/T2DM burden. The Bayesian Age-Period-Cohort (BAPC) model and the Nordpred model projected the burden through 2040.

Results In 2021, the prevalence of SHF-CKD-T1DM was 5723 (95% UI: 4397 to 7284) and SHF-CKD-T2DM was 122,404 (95% UI: 89,920 to 169,580). The age-standardised years lived with disability (YLDs) rates for SHF-CKD-T1DM in 2021 exhibited a significant increase to 0.012 (95% UI: 0.008 to 0.019), while YLDs rates for SHF-CKD-T2DM also showed a notable rise to 0.249 (95% UI: 0.146 to 0.394). The global burden of SHF-CKD-T1/T2DM showed variability across different sociodemographic index (SDI) regions. In 2021, the overall burden of SHF-CKD-T1/T2DM continued to increase, with age being a significant contributor. Similarly, SHF-CKD-T1/T2DM burden exhibited gender-specific variability. Decomposition analysis indicated that epidemiological changes were the primary contributors to the global burden of prevalence and YLDs associated with SHF-CKD-T1/T2DM. It is projected that by 2040, the trends in prevalence and YLDs will stabilise; however, they are expected to continue rising.

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Conclusion The increasing burden of SHF-CKD-T1/T2DM is driven by epidemiological transitions, population growth, and regional disparities. Although growth rates have decelerated, the rising number of cases highlights the urgent need for targeted prevention and early intervention strategies in high-risk populations. To alleviate this burden, it is essential to address metabolic determinants, improve healthcare access in regions with high prevalence, expand diabetes treatment coverage in low-SDI regions, and incorporate cardiorenal risk stratification into diabetes management frameworks.

Key words: heart failure; chronic kidney disease; diabetes mellitus; global burden; risk factors; epidemiologic study

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Introduction

Diabetes mellitus (DM) has emerged as a significant chronic health burden in the 21st century, affecting an estimated 529 million individuals globally (GBD 2021 Diabetes Collaborators, 2023). Its associated complications present a multifaceted health challenge, with chronic kidney disease (CKD) receiving considerable attention due to its high prevalence and associated disability; approximately half of individuals with type 2 diabetes mellitus (T2DM) and one-third of those with type 1 diabetes mellitus (T1DM) are expected to develop CKD (Thomas et al, 2015). Recent large-scale cohort studies have reported CKD as a significant independent risk factor for heart failure (HF) among patients with diabetes mellitus (Birkeland et al, 2020; Vijay et al, 2022; Wu et al, 2023). Additionally, the coexistence of DM and CKD is associated with a 33% higher risk of cardiovascular mortality compared to DM alone in chronic heart failure patients (Hazard Ratio = 1.33, 95% confidence interval [CI]: 1.07 to 1.66) (Ekundayo et al, 2009). This heart-kidney interaction, commonly known as cardiorenal syndrome, poses a significant challenge in the management of diabetes (Eliasson et al, 2022; Vijay et al, 2022).

Severe heart failure (SHF) secondary to chronic kidney disease (CKD) in type 1/2 diabetes mellitus (T1/T2DM) constitutes a complex cardiorenal syndrome originating from left ventricular remodelling secondary to T1/T2DM-induced CKD. Its pathophysiological features encompass myocardial hypertrophy, elevated arterial stiffening, and rhythm disturbances arising from chronic uremic toxicity and volume dysregulation (Matsushita et al, 2022; Omote et al, 2022; Pitt et al, 2021). Clinically, it manifests as severe dyspnea at rest, or orthopnea, or paroxysmal nocturnal dyspnea; refractory oedema with hepatomegaly and jugular distension; and New York Heart Association (NYHA) III–IV functional impairment. Concurrent signs often include pulmonary rales and hypoperfusion markers such as cool extremities and progressive renal abnormalities (Greene et al, 2021). This condition imposes a substantial societal and healthcare burden (Johansson et al, 2021).

While the individual disease burdens of DM, CKD, and SHF have been extensively investigated, a comprehensive global assessment of the causal chain linking "SHF-CKD-T1/T2DM" remains insufficient. Most studies to date are confined to individual countries or specific populations without uniform, cross-country com-

parison methodologies. Furthermore, there is a scarcity of studies quantifying the attributable risk of SHF events, specifically in diabetic patients with CKD.

Utilising the Global Burden of Disease (GBD) study 2021 data, this research represents the first comprehensive evaluation of the epidemiological burden of SHF attributable to CKD within a diabetic population. By analysing trends in prevalence and years lived with disability (YLDs) from 1990 to 2021, the study aims to elucidate variation across geographic regions, age groups, sexes, and sociodemographic index (SDI) strata. Such evidence is crucial for interrupting the detrimental "glycemic-renal-cardio comorbidity cycle".

Methods

Data Sources

Epidemiological data were derived from the GBD 2021 (http://www.healthdata.org), including YLDs linked to SHF-CKD-T1/T2DM across multi-tiered geographical scales (global, regional, and country-specific), alongside population metrics from the SDI framework (GBD 2019 Diseases and Injuries Collaborators, 2020). A stratified analysis of SHF-CKD-T1/T2DM morbidity was conducted using age and sex-disaggregated demographic data across 204 distinct geographical regions (GBD 2017 DALYs and HALE Collaborators, 2018; GBD 2017 Population and Fertility Collaborators, 2018). The GBD employs an integrative meta-regression approach to address data paucity and heterogeneity, generating harmonised epidemiological estimates of prevalence and YLDs as the principal composite measure for non-fatal health outcomes (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018). The SDI is a composite index integrating three core dimensions: per capita gross domestic product (GDP) to reflect economic capacity, average educational attainment among individuals aged $\geq$15 years to indicate human capital, and fertility rates among women under 25 years to capture demographic dynamics. Scaled from 0–1, the SDI stratifies regions into developmental strata, where 0 indicates low development (characterised by high fertility rates, limited education, and low income) and 1 denotes advanced development (marked by low fertility, high educational attainment, and robust economic output).

Using 2019 reference values, the GBD database classifies 204 countries and territories into five quintiles:

(1) Low SDI (e.g., Afghanistan, Haiti);
(2) Low-middle SDI (e.g., Bangladesh, Cameroon);
(3) Middle SDI (e.g., China, Brazil);
(4) High-middle SDI (e.g., Argentina, Chile);
(5) High SDI (e.g., Canada, France).

This stratification enables comparative analysis of health outcomes across socioeconomic gradients, revealing disparities in disease burden, healthcare access, and mortality patterns. For instance, low SDI regions exhibit a higher burden of infectious diseases and maternal-child mortality, whereas high SDI regions face elevated rates of non-communicable diseases. By capturing multiple dimensions of development, the SDI provides significant insights into global health challenges

and facilitates targeted policy interventions and resource allocation (GBD 2019 Demographics Collaborators, 2020).

In this study, the International Classification of Diseases 10th Revision (ICD-10) codes were utilised as follows: E10 is for T1DM, E11 for T2DM, and N18 for CKD. CKD was further specified by codes N18.1 to N18.5, corresponding to stages 1 through 5. According to the revised ICD-10 system, heart failure is represented with code 150 and its subcodes, such as I50.0 (congestive heart failure), I50.1 (left ventricular failure), and I50.9 (unspecified heart failure). Severe heart failure (SHF) was identified by the presence of code 150 in combination with NYHA grade III (severe limitation of activity) or IV (symptoms at rest) (Caraballo et al, 2019). Existing evidence suggests that ICD-10 coding accurately defines T1DM, T2DM, CKD, and SHF within the data sources utilised to construct this database.

Descriptive Analysis

A comprehensive assessment was performed to quantify the global, regional and national burden of SHF-CKD-T1/T2DM by assessing both prevalence and YLDs. Spatiotemporal visualisations were generated to determine case incidence, unadjusted prevalence metrics, and age-standardised rates (ASR) for SHF-CKD-T1/T2DM's level from 1990 to 2021, including epidemiological prevalence and YLDs worldwide. Additionally, a comparative analysis was conducted to evaluate case numbers and ASRs for SHF-CKD-T1/T2DM between 1990 and 2021 at the global level across five SDI dimensions, 21 regions, and 204 countries. The 95% uncertainty interval (UI) reported in the GBD database reflects a Bayesian probability, indicating a 95% likelihood that the true value lies within the interval after accounting for data variability and model assumptions. Statistical significance was determined by a $p < 0.05$, which rejects the null hypothesis under frequentist frameworks, suggesting that observed differences are unlikely to be due to chance. In this framework, UI quantifies the precision of estimates, whereas p-values assess the probability that observed differences reflect true effects, with $p < 0.05$ denoting significance.

Trend Analysis

To characterise longitudinal disease burden dynamics in SHF-CKD-T1/T2DM, this investigation analysed global and subnational trends in prevalence and disability-adjusted metrics. ASR were measured using GBD data to adjust for demographic heterogeneity and separate true disease burden trends from age-structure effects. Estimated annual percentage changes (EAPC) in ASR were calculated to assess trajectory trends, with trends classified as increasing, decreasing, or stable based on whether the EAPC confidence intervals showed a consistent rise, decline, or no substantial change. The GBD's Bayesian meta-regression methodology integrates diverse data sources to minimise bias and enhance comparability, enabling detailed risk attribution and future burden projections.

Table 1. Global SHF-CKD-T1/2DM prevalence by SDI in 1990 and 2021, as well as changes in trends from 1990 to 2021.

Location	Sex	SHF-CKD-T1DM					SHF-CKD-T2DM				
		Prevalence cases (95% UI)-1990	ASPR (Per 100,000 population)-1990	Prevalence cases (95% UI)-2021	ASPR (Per 100,000 population)-2021	1990–2021 EAPC, No. (95% CI)	Prevalence cases (95% UI)-1990	ASPR (Per 100,000 population)-1990	Prevalence cases (95% UI)-2021	ASPR (Per 100,000 population)-2021	1990–2021 EAPC, No. (95% CI)
Global	Both	1636 (1278 to 2071)	0.033 (0.026 to 0.042)	5723 (4397 to 7284)	0.069 (0.053 to 0.088)	2.85 (2.72 to 2.97)	28,577 (21,090 to 38,700)	0.757 (0.557 to 1.015)	122,404 (89,920 to 169,580)	1.423 (1.041 to 1.964)	2.26 (2.16 to 2.36)
Global	Female	660 (518 to 842)	0.027 (0.021 to 0.034)	2411 (1854 to 3127)	0.057 (0.044 to 0.074)	2.96 (2.81 to 3.10)	14,157 (10,510 to 19,061)	0.670 (0.499 to 0.896)	62,772 (46,312 to 86,697)	1.347 (0.996 to 1.862)	2.51 (2.41 to 2.62)
Global	Male	976 (756 to 1252)	0.040 (0.031 to 0.050)	3312 (2541 to 4241)	0.081 (0.063 to 0.103)	2.77 (2.65 to 2.89)	14,420 (10,584 to 19,564)	0.888 (0.650 to 1.196)	59,632 (43,661 to 82,519)	1.532 (1.122 to 2.116)	1.94 (1.85 to 2.03)
Sociodemographic index											
High SDI	Both	312 (243 to 408)	0.032 (0.025 to 0.042)	1308 (977 to 1800)	0.084 (0.063 to 0.111)	3.86 (3.66 to 4.06)	6426 (4621 to 8853)	0.566 (0.412 to 0.770)	32,634 (23,529 to 45,128)	1.454 (1.063 to 1.985)	3.49 (3.29 to 3.68)
High SDI	Female	157 (119 to 210)	0.031 (0.023 to 0.041)	618 (451 to 858)	0.079 (0.058 to 0.109)	3.83 (3.62 to 4.04)	3683 (2685 to 5137)	0.549 (0.407 to 0.750)	17,306 (12,692 to 23,940)	1.403 (1.039 to 1.909)	3.58 (3.36 to 3.80)
High SDI	Male	155 (121 to 201)	0.033 (0.026 to 0.043)	690 (516 to 934)	0.089 (0.068 to 0.119)	3.88 (3.69 to 4.07)	2744 (1918 to 3791)	0.605 (0.427 to 0.831)	15,328 (10,861 to 21,336)	1.534 (1.096 to 2.118)	3.30 (3.13 to 3.48)
High-middle SDI	Both	198 (151 to 260)	0.019 (0.014 to 0.025)	685 (519 to 904)	0.043 (0.032 to 0.055)	3.10 (2.97 to 3.22)	4526 (3366 to 6151)	0.472 (0.350 to 0.639)	18,820 (13,765 to 26,476)	0.931 (0.686 to 1.293)	2.46 (2.34 to 2.59)
High-middle SDI	Female	91 (68 to 124)	0.017 (0.012 to 0.023)	314 (229 to 413)	0.039 (0.029 to 0.052)	3.16 (3.04 to 3.27)	2356 (1745 to 3192)	0.416 (0.310 to 0.560)	10,065 (7369 to 14,138)	0.898 (0.661 to 1.259)	2.73 (2.63 to 2.83)
High-middle SDI	Male	107 (82 to 140)	0.021 (0.016 to 0.028)	371 (284 to 491)	0.047 (0.036 to 0.062)	3.05 (2.90 to 3.20)	2169 (1582 to 2944)	0.573 (0.420 to 0.788)	8755 (6400 to 12,301)	0.991 (0.729 to 1.364)	2.05 (1.90 to 2.20)
Low SDI	Both	288 (200 to 451)	0.075 (0.052 to 0.107)	946 (654 to 1442)	0.108 (0.076 to 0.156)	1.53 (1.44 to 1.62)	3660 (2456 to 5332)	1.963 (1.311 to 2.794)	10,064 (6800 to 14,509)	2.347 (1.577 to 3.379)	0.56 (0.50 to 0.62)
Low SDI	Female	86 (57 to 141)	0.046 (0.032 to 0.067)	297 (202 to 460)	0.070 (0.049 to 0.104)	1.59 (1.51 to 1.66)	1624 (1092 to 2350)	1.758 (1.189 to 2.530)	4777 (3222 to 6885)	2.147 (1.434 to 3.103)	0.63 (0.55 to 0.70)
Low SDI	Male	202 (139 to 315)	0.103 (0.072 to 0.146)	649 (447 to 979)	0.146 (0.102 to 0.211)	1.54 (1.43 to 1.65)	2036 (1369 to 2952)	2.172 (1.443 to 3.107)	5287 (3570 to 7659)	2.570 (1.732 to 3.701)	0.54 (0.49 to 0.59)
Low-middle SDI	Both	357 (252 to 508)	0.037 (0.027 to 0.049)	1105 (803 to 1481)	0.061 (0.045 to 0.082)	1.84 (1.76 to 1.92)	5062 (3750 to 6740)	0.957 (0.695 to 1.279)	17,833 (12,940 to 24,534)	1.328 (0.965 to 1.816)	0.98 (0.92 to 1.04)
Low-middle SDI	Female	127 (88 to 179)	0.027 (0.019 to 0.036)	441 (307 to 618)	0.048 (0.034 to 0.067)	2.15 (2.05 to 2.25)	2172 (1616 to 2892)	0.816 (0.603 to 1.100)	8489 (6147 to 11,570)	1.186 (0.861 to 1.619)	1.15 (1.07 to 1.23)
Low-middle SDI	Male	230 (164 to 327)	0.046 (0.033 to 0.061)	664 (489 to 885)	0.074 (0.054 to 0.098)	1.69 (1.61 to 1.78)	2890 (2123 to 3872)	1.100 (0.795 to 1.473)	9345 (6760 to 12,922)	1.499 (1.077 to 2.062)	0.91 (0.87 to 0.96)

Table 1. Continued.

Location	Sex	SHF-CKD-T1DM					SHF-CKD-T2DM				
		Prevalence cases (95% UI)-1990	ASPR (Per 100,000 population)-1990	Prevalence cases (95% UI)-2021	ASPR (Per 100,000 population)-2021	1990–2021 EAPC, No. (95% CI)	Prevalence cases (95% UI)-1990	ASPR (Per 100,000 population)-1990	Prevalence cases (95% UI)-2021	ASPR (Per 100,000 population)-2021	1990–2021 EAPC, No. (95% CI)
Middle SDI	Both	479 (346 to 638)	0.030 (0.023 to 0.039)	1675 (1246 to 2198)	0.063 (0.047 to 0.082)	2.82 (2.67 to 2.97)	8877 (6651 to 11,841)	0.962 (0.724 to 1.293)	42,961 (31,219 to 59,952)	1.632 (1.196 to 2.265)	1.90 (1.79 to 2.01)
Middle SDI	Female	198 (142 to 266)	0.025 (0.019 to 0.033)	740 (543 to 985)	0.055 (0.040 to 0.074)	2.96 (2.80 to 3.13)	4310 (3240 to 5776)	0.865 (0.650 to 1.155)	22,090 (16,077 to 30,607)	1.569 (1.147 to 2.166)	2.09 (1.97 to 2.20)
Middle SDI	Male	282 (206 to 372)	0.035 (0.027 to 0.046)	935 (693 to 1203)	0.071 (0.053 to 0.091)	2.73 (2.59 to 2.87)	4567 (3420 to 6089)	1.092 (0.819 to 1.465)	20,871 (15,130 to 29,230)	1.726 (1.267 to 2.389)	1.70 (1.58 to 1.82)

SHF-CKD-T1/T2DM, severe heart failure (SHF) secondary to chronic kidney disease (CKD) in type 1/2 diabetes mellitus (T1/T2DM); UI, uncertainty interval; CI, confidence interval; SDI, sociodemographic index; EAPC, estimated annual percentage changes; ASPR, age-standardised prevalence rate.

Table 2. Global SHF-CKD-T1/2DM YLDs by SDI in 1990 and 2021, as well as changes in trends from 1990 to 2021.

Location	Sex	SHF-CKD-T1DM					SHF-CKD-T2DM				
		YLDs cases (95% UI)-1990	ASYR (Per 100,000 population)-1990	YLDs cases (95% UI)-2021	ASYR (Per 100,000 population)-2021	1990–2021 EAPC, No. (95% CI)	YLDs cases (95% UI)-1990	ASYR (Per 100,000 population)-1990	YLDs cases (95% UI)-2021	ASYR (Per 100,000 population)-2021	1990–2021 EAPC, No. (95% CI)
Global	Both	293 (181 to 443)	0.006 (0.004 to 0.009)	1026 (623 to 1594)	0.012 (0.008 to 0.019)	2.85 (2.72 to 2.97)	5045 (2939 to 7906)	0.133 (0.078 to 0.211)	21,422 (12,539 to 33,774)	0.249 (0.146 to 0.394)	2.23 (2.13 to 2.32)
Global	Female	118 (73 to 181)	0.005 (0.003 to 0.007)	432 (260 to 671)	0.010 (0.006 to 0.016)	2.96 (2.82 to 3.10)	2504 (1452 to 3907)	0.118 (0.069 to 0.184)	10,993 (6446 to 17,338)	0.236 (0.138 to 0.371)	2.48 (2.37 to 2.58)
Global	Male	175 (108 to 264)	0.007 (0.004 to 0.011)	594 (359 to 916)	0.015 (0.009 to 0.022)	2.77 (2.65 to 2.89)	2540 (1471 to 3982)	0.156 (0.090 to 0.247)	10,429 (6090 to 16,653)	0.267 (0.157 to 0.427)	1.92 (1.84 to 2.01)
Sociodemographic index											
High SDI	Both	56 (34 to 86)	0.006 (0.003 to 0.009)	235 (137 to 375)	0.015 (0.009 to 0.023)	3.86 (3.66 to 4.06)	1147 (655 to 1814)	0.101 (0.059 to 0.159)	5705 (3264 to 9162)	0.255 (0.146 to 0.406)	3.41 (3.22 to 3.6)
High SDI	Female	28 (17 to 43)	0.006 (0.003 to 0.009)	111 (65 to 174)	0.014 (0.008 to 0.022)	3.83 (3.62 to 4.04)	658 (378 to 1036)	0.098 (0.058 to 0.156)	3027 (1754 to 4798)	0.246 (0.144 to 0.393)	3.50 (3.29 to 3.71)

Table 2. Continued.

Location	Sex	SHF-CKD-T1DM					SHF-CKD-T2DM				
		YLDs cases (95% UI)-1990	ASYR (Per 100,000 population)-1990	YLDs cases (95% UI)-2021	ASYR (Per 100,000 population)-2021	1990–2021 EAPC, No. (95% CI)	YLDs cases (95% UI)-1990	ASYR (Per 100,000 population)-1990	YLDs cases (95% UI)-2021	ASYR (Per 100,000 population)-2021	1990–2021 EAPC, No. (95% CI)
High SDI	Male	28 (17 to 42)	0.006 (0.004 to 0.009)	124 (72 to 196)	0.016 (0.009 to 0.025)	3.88 (3.69 to 4.07)	489 (280 to 778)	0.108 (0.061 to 0.170)	2678 (1512 to 4351)	0.268 (0.152 to 0.432)	3.24 (3.07 to 3.41)
High-middle SDI	Both	36 (22 to 55)	0.003 (0.002 to 0.005)	123 (71 to 191)	0.008 (0.005 to 0.012)	3.10 (2.97 to 3.23)	808 (469 to 1275)	0.084 (0.048 to 0.133)	3317 (1916 to 5314)	0.164 (0.095 to 0.261)	2.42 (2.30 to 2.54)
High-middle SDI	Female	16 (10 to 26)	0.003 (0.002 to 0.005)	56 (33 to 89)	0.007 (0.004 to 0.011)	3.16 (3.05 to 3.28)	421 (242 to 666)	0.074 (0.043 to 0.117)	1776 (1025 to 2877)	0.159 (0.092 to 0.254)	2.68 (2.58 to 2.78)
High-middle SDI	Male	19 (12 to 30)	0.004 (0.002 to 0.006)	67 (39 to 104)	0.008 (0.005 to 0.013)	3.05 (2.90 to 3.20)	387 (226 to 608)	0.102 (0.058 to 0.158)	1541 (894 to 2458)	0.174 (0.100 to 0.278)	2.01 (1.87 to 2.16)
Low SDI	Both	52 (28 to 89)	0.013 (0.007 to 0.023)	170 (91 to 280)	0.019 (0.011 to 0.032)	1.53 (1.44 to 1.62)	633 (345 to 1076)	0.336 (0.184 to 0.556)	1744 (963 to 2893)	0.404 (0.219 to 0.670)	0.57 (0.51 to 0.63)
Low SDI	Female	16 (8 to 28)	0.008 (0.004 to 0.014)	53 (29 to 94)	0.013 (0.007 to 0.022)	1.59 (1.51 to 1.66)	281 (154 to 474)	0.301 (0.164 to 0.513)	825 (457 to 1399)	0.368 (0.203 to 0.632)	0.64 (0.57 to 0.71)
Low SDI	Male	36 (19 to 63)	0.018 (0.010 to 0.032)	116 (62 to 192)	0.026 (0.015 to 0.043)	1.54 (1.43 to 1.65)	352 (192 to 599)	0.372 (0.204 to 0.627)	919 (499 to 1532)	0.443 (0.239 to 0.742)	0.55 (0.49 to 0.60)
Low-middle SDI	Both	64 (38 to 101)	0.007 (0.004 to 0.010)	198 (119 to 316)	0.011 (0.007 to 0.017)	1.84 (1.76 to 1.92)	887 (517 to 1405)	0.167 (0.097 to 0.266)	3119 (1803 to 4952)	0.231 (0.131 to 0.368)	0.98 (0.92 to 1.04)
Low-middle SDI	Female	23 (13 to 38)	0.005 (0.003 to 0.008)	79 (46 to 128)	0.009 (0.005 to 0.014)	2.15 (2.05 to 2.25)	381 (223 to 607)	0.142 (0.081 to 0.227)	1485 (860 to 2351)	0.207 (0.120 to 0.330)	1.15 (1.07 to 1.24)
Low-middle SDI	Male	41 (24 to 65)	0.008 (0.005 to 0.013)	119 (72 to 186)	0.013 (0.008 to 0.021)	1.69 (1.61 to 1.78)	507 (294 to 799)	0.192 (0.110 to 0.302)	1633 (936 to 2613)	0.261 (0.147 to 0.413)	0.91 (0.87 to 0.95)
Middle SDI	Both	86 (52 to 130)	0.005 (0.003 to 0.008)	300 (180 to 459)	0.011 (0.007 to 0.017)	2.82 (2.67 to 2.97)	1566 (929 to 2429)	0.169 (0.099 to 0.265)	7522 (4444 to 12,047)	0.285 (0.169 to 0.456)	1.88 (1.77 to 1.99)
Middle SDI	Female	35 (21 to 56)	0.005 (0.003 to 0.007)	133 (79 to 208)	0.010 (0.006 to 0.016)	2.96 (2.80 to 3.13)	762 (452 to 1183)	0.152 (0.090 to 0.239)	3872 (2263 to 6072)	0.275 (0.160 to 0.430)	2.06 (1.95 to 2.17)
Middle SDI	Male	50 (31 to 78)	0.006 (0.004 to 0.010)	168 (101 to 255)	0.013 (0.008 to 0.019)	2.73 (2.59 to 2.87)	804 (469 to 1250)	0.191 (0.112 to 0.298)	3650 (2175 to 5999)	0.301 (0.174 to 0.486)	1.69 (1.57 to 1.81)

YLDs, years lived with disability; ASYR, age-standardised years lived with disability rate.

Decomposition Analysis

To better understand the factors driving changes in YLDs for SHF-CKD-T1/T2DM between 1990 and 2021 and to clarify the extent to which population growth, ageing and epidemiological changes have contributed to shifts in SHF-CKD-T1/T2DM epidemiology, this study conducted a decomposition analysis. This analysis divided the observed YLD changes into components linked to population growth, variations in age structure, and epidemiological changes, defined here as the differences in population- and age-standardised YLDs (Xie et al, 2018).

Predictive Analysis

This study employed a hierarchical Bayesian Age-Period-Cohort (BAPC) framework on the GBD database to project sex-stratified ASR of SHF-CKD-T1/T2DM populations through 2040. The BAPC model addresses identifiability challenges common in traditional APC models by incorporating hierarchical priors to stabilise parameter estimation, decomposing temporal trends into distinct age, period, and cohort components. The posterior inference was determined efficiently by employing the Integrated Nested Laplace Approximation (INLA). Concurrently, the Nordpred model complemented projections by incorporating power-link functions and cohort-specific drift parameters to extrapolate age-period trends. Together, these methods reconciled temporal confounding and demographic heterogeneity, enabling robust long-term burden projections and risk attribution.

All statistical computations were performed with the open-source computational platform R (version 4.4.1, R Development Core Team, Vienna, Austria).

Results

Global Burden of SHF-CKD-T1/T2DM

Tables 1,2 show that in 2021, the all-age prevalence of SHF-CKD-T1/T2DM was 5723 (95% UI: 4397 to 7284) for T1DM and 122,404 (95% UI: 89,920 to 169,580) for T2DM. In contrast, in 1990, the prevalence of SHF-CKD-T1DM was 1636 (95% UI: 1278 to 2071), while that of SHF-CKD-T2DM was 28,577 (95% UI: 21,090 to 38,700). The YLDs associated with SHF-CKD-T1DM increased from 293 (95% UI: 181 to 443) in 1990 to 1026 (95% UI: 623 to 1594) in 2021. Similarly, the YLDs for SHF-CKD-T2DM rose from 5045 (95% UI: 2939 to 7906) in 1990 to 21,422 (95% UI: 12,539 to 33,774) in 2021.

In 1990, the ASR of YLDs for SHF-CKD-T1DM was 0.006 (95% UI: 0.004 to 0.009), increasing to 0.012 (95% UI: 0.008 to 0.019) by 2021, with an EAPC of 2.85 (95% CI: 2.72 to 2.97) as depicted in Fig. 1A. Similarly, the ASR of YLDs for SHF-CKD-T2DM was 0.133 (95% UI: 0.078 to 0.211) in 1990, rising to 0.249 (95% UI: 0.146 to 0.394) in 2021, with an EAPC of 2.23 (95% CI: 2.13 to 2.32), as shown in Fig. 1A. Collectively, these results indicate a significant increase in disease burden between 1990 and 2021.

GBD 2021 data revealed significant sex-based disparities. Age-stratified analyses showed that males had higher prevalence and YLDs than females in both 1990 and 2021; however, the EAPC analysis showed the opposite trend (e.g., YLDs

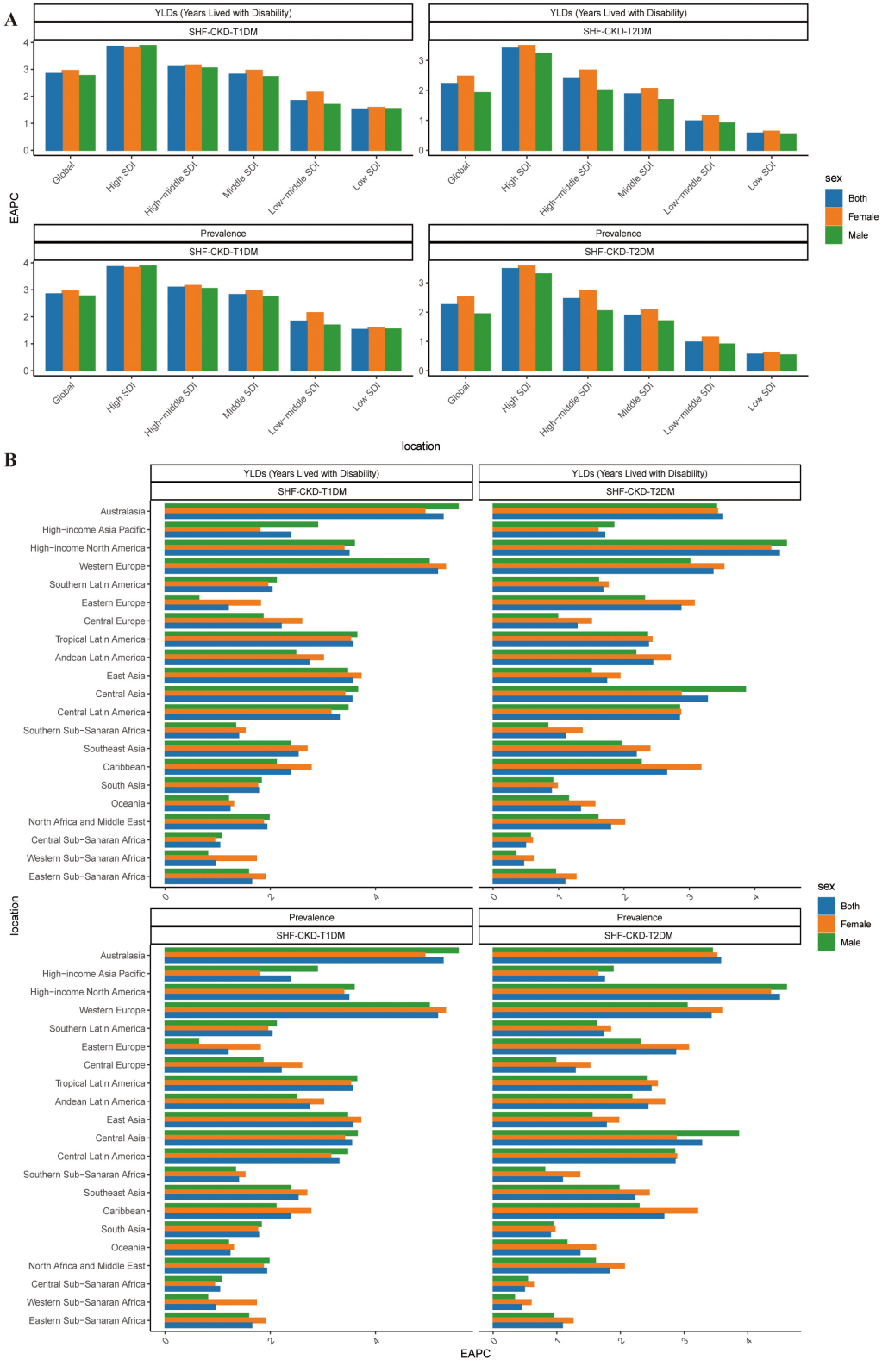

Fig. 1. The trends in the burden of severe heart failure (SHF) secondary to chronic kidney disease (CKD) in type 1/2 diabetes mellitus (T1/T2DM) were analysed by estimated annual percentage change (EAPC) in 2021. (A) The EAPC of the global and socio-demographic index (SDI). (B) The EAPC of regions.

EAPC for SHF-CKD-T1DM: male 2.77 [95% CI: 2.65 to 2.89] vs. female 2.96 [95% CI: 2.81 to 3.1]) (Tables 1,2 and Fig. 1A). In SHF-CKD-T1DM, the highest disease burden was observed in the 65–69 age group, whereas in SHF-CKD-T2DM, the peak disease burden was primarily in the 70–74 age group (Fig. 2A). Furthermore, the ASR of the disease burden peak shifted to the 85–89 age group in the context of SHF-CKD-T2DM (Fig. 2B).

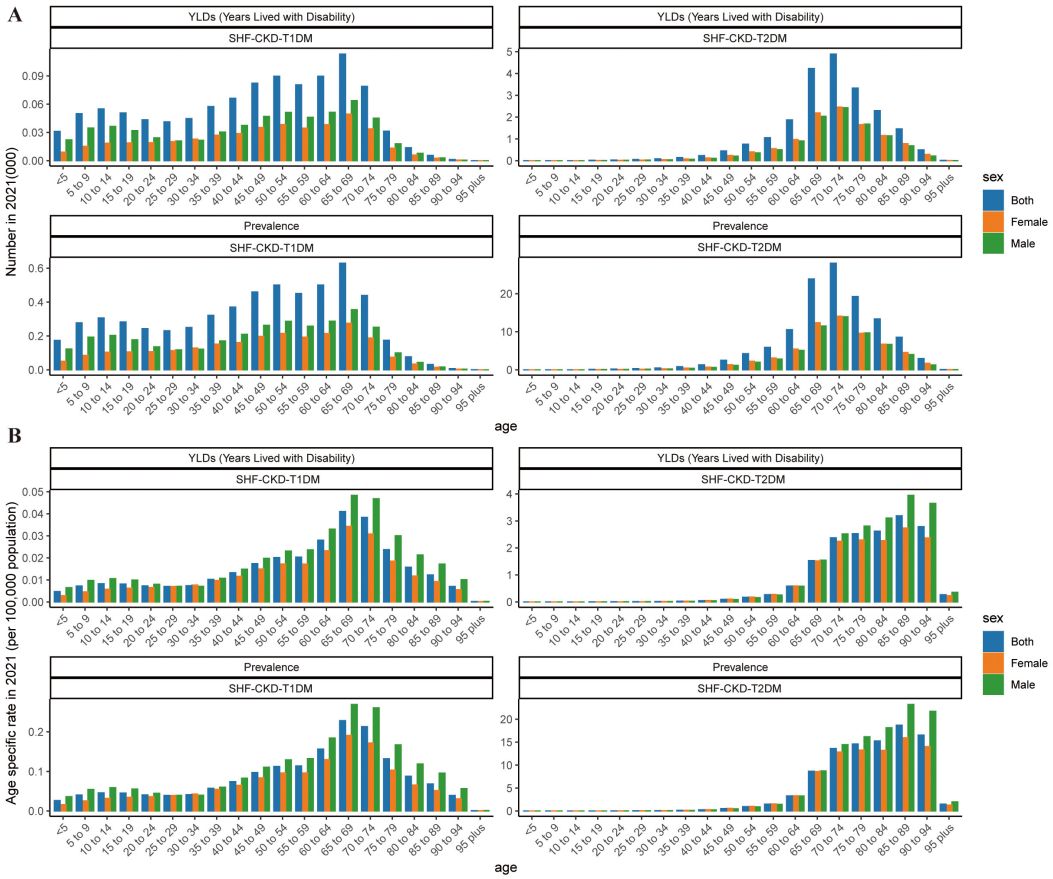

Fig. 2. Age patterns of years lived with disability (YLDs) and prevalence of SHF-CKD-T1/T2DM by sex in 2021. (A) Number of YLDs and number of cases. (B) Age-standardised YLD rates and age-standardised prevalence rates per 100,000 population.

The Spatial Distribution of the Burden of SHF-CKD-T1/T2DM

The prevalence and YLDs of SHF-CKD-T1/T2DM were highest in middle SDI regions (Tables 1,2). However, the higher ASR rates were found in low SDI regions (Tables 1,2). Additionally, EAPC analysis from GBD 2021 indicated a significant increasing trend in high SDI regions (Fig. 1A,B and Tables 1,2).

Among the 21 GBD regions, Western Sub-Saharan Africa and Southeast Asia demonstrated the highest prevalence and YLDs for SHF-CKD-T1DM, whereas East Asia and High-income North America showed the highest prevalence and YLDs for SHF-CKD-T2DM. The ASR for the highest prevalence and YLDs in SHF-CKD-T1DM were observed in Southern, Eastern, and Western Sub-Saharan Africa. In the case of SHF-CKD-T2DM, the highest ASR was noted in Western Sub-

Saharan Africa and Andean/Central Latin America. Furthermore, Australasia and Western Europe exhibited the highest EAPC in burden for SHF-CKD-T1/T2DM (Fig. 1B and **Supplementary Tables 1,2**).

The national-level epidemiological burden of SHF-CKD-T1/T2DM, as quantified through the ASR of YLDs and prevalence analyses, was highest in Nigeria (1.66, 95% UI: 0.93 to 2.79), El Salvador (1.136, 95% UI: 0.65 to 1.795), Nicaragua (0.967, 95% UI: 0.528 to 1.486), Guatemala (0.967, 95% UI: 0.512 to 1.503), and Mexico (0.957, 95% UI: 0.568 to 1.513) (Fig. 3).

The estimation between SDI and the ASR of SHF-CKD-T1/T2DM YLDs and prevalence was generally positive across the 21 regions, with the slope steepening at higher SDI (Fig. 4A). Western Sub-Saharan Africa consistently showed higher ASR of YLDs and prevalence that exceeded those predicted by its SDI for every year between 1990 and 2021. The global locations analysis suggested that the ASR of YLDs and prevalence were lower in locations with SDI, and a more clustered distribution was found in these locations (Fig. 4B).

Longitudinal analysis from 1990 to 2021 showed a significant increase in SHF-CKD-T1/T2DM burden, as quantified by YLDs and prevalence metrics. Epidemiologic patterns demonstrate a consistent progression of disease burden across all regions, with disproportionately higher growth rates observed in high SDI regions (Fig. 5A). Sex-specific analysis indicated that both males and females experienced increases in burden, with slight variations in prevalence and YLDs between the sexes. Although the upward growth trend persisted for both men and women, the rate of increase gradually decelerated after 2020 (Fig. 5B).

Overall, these findings underscore the increasing burden of SHF-CKD-T1/T2DM and emphasise the need for targeted interventions in high-burden regions.

Decomposition Analysis of YLDs and Prevalence for SHF-CKD-T1/T2DM

The impact of ageing, population growth, and epidemiological changes on SHF-CKD-T1/T2DM burden was assessed using a decomposition analysis of YLDs and prevalence. Globally, YLDs and prevalence for SHF-CKD-T1/T2DM significantly increased over the past 31 years, with the most pronounced rise observed in high-SDI countries. In the case of SHF-CKD-T1DM, ageing, population growth, and epidemiological changes contributed 28.57%, 79.11%, and 142.25% of the increase in global YLDs, and 28.56%, 79.10% and 142.17% in global prevalence increase. Regionally, ageing had the highest impact in high-SDI countries (47.32%), population growth was the leading contributor in low-SDI countries (151.44%), and epidemiological changes contributed the most in high-SDI countries (221.62%) (Fig. 6A).

In the case of SHF-CKD-T2DM, ageing, population growth and epidemiological changes contributed 76.34%, 110.62% and 137.68% to the global YLDs increase and 77.14%, 111.26% and 139.93% to the global prevalence increase, respectively. Regionally, ageing contributed the most in middle-SDI countries (127.86%), population growth had the largest contribution in low-SDI countries (151.53%), and epidemiological changes had the greatest impact in high-SDI countries (225.70%). These results indicate that epidemiological changes and population growth are the

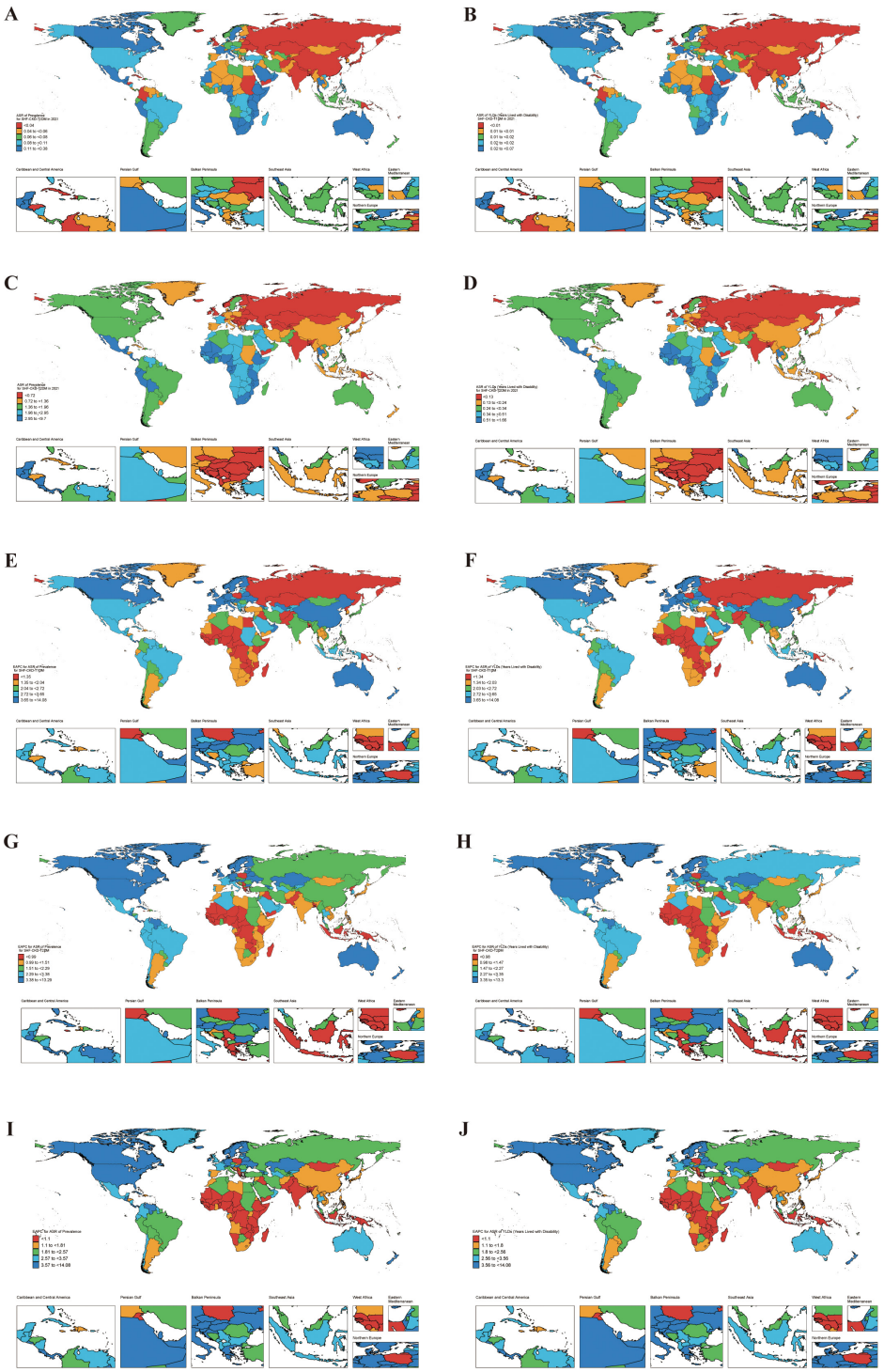

Fig. 3. Global SHF-CKD-T1/T2DM disease burden by country in 2021 and trends in disease burden changes across countries between 1990 and 2021. (A) The age-standardised prevalence rate (ASPR) of SHF-CKD-T1DM in 2021. (B) The age-standardised years lived with disability rate (ASYR) of SHF-CKD-T1DM in 2021. (C) The ASPR of SHF-CKD-T2DM in 2021. (D) The ASYR of SHF-CKD-T2DM in 2021. (E) The EAPC for ASPR of SHF-CKD-T1DM. (F) The EAPC for ASYR of SHF-CKD-T1DM. (G) The EAPC for ASPR of SHF-CKD-T2DM. (H) The EAPC for ASYR of SHF-CKD-T2DM. (I) The EAPC for ASPR of SHF-CKD-T1/T2DM. (J) The EAPC for ASYR of SHF-CKD-T1/T2DM.

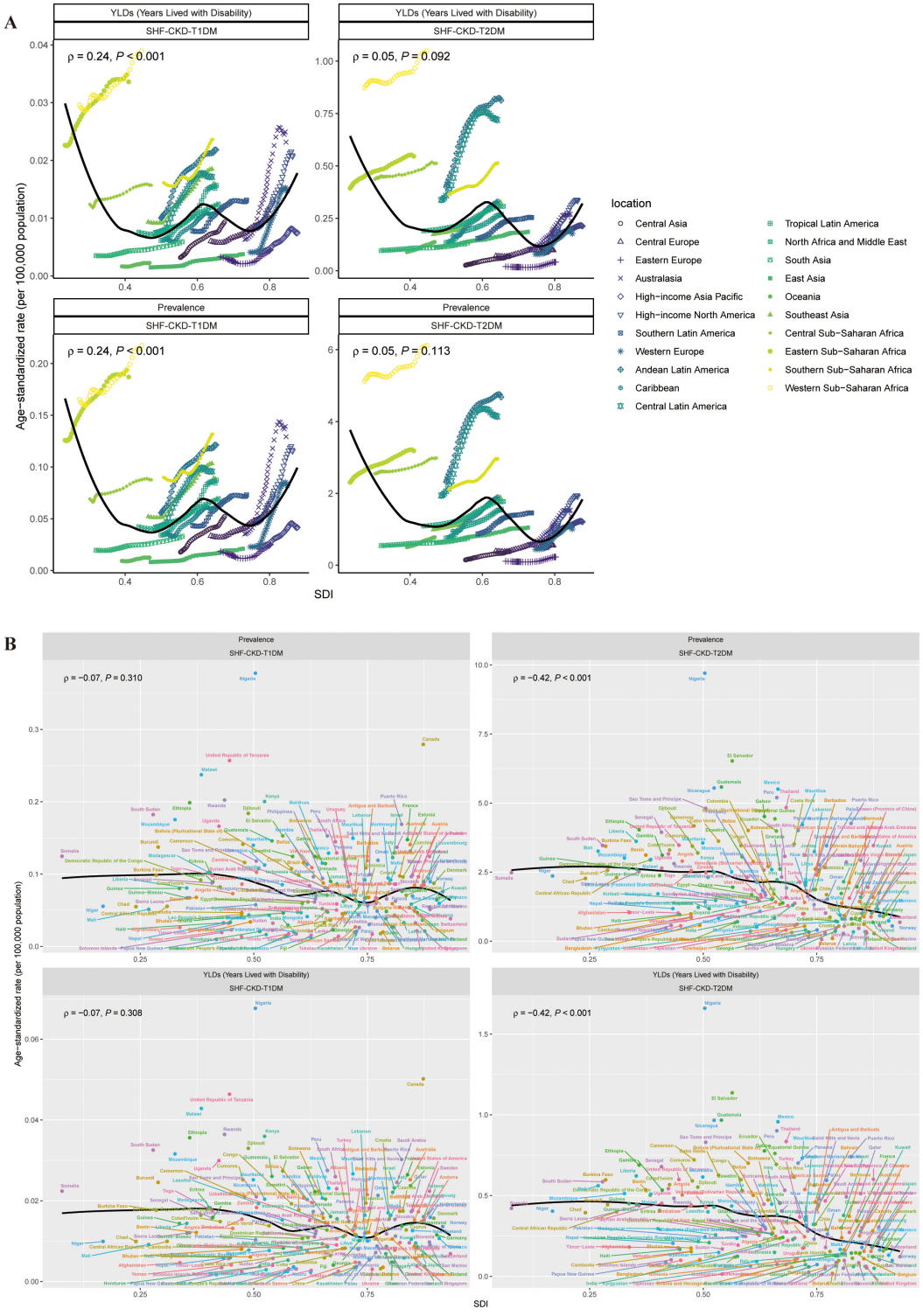

Fig. 4. ASPR and ASYR of SHF-CKD-T1/T2DM for global countries and 21 regions by SDI between 1990 and 2021. (A) ASPR and ASYR of SHF-CKD-T1/T2DM for 21 regions by SDI. (B) ASPR and ASYR of SHF-CKD-T1/T2DM for global countries. Black lines show the expected YLDs or prevalence rates based on the sociodemographic index (SDI) alone.

primary contributors to the global SHF-CKD-T1/T2DM burden in terms of YLDs and prevalence (Fig. 6B).

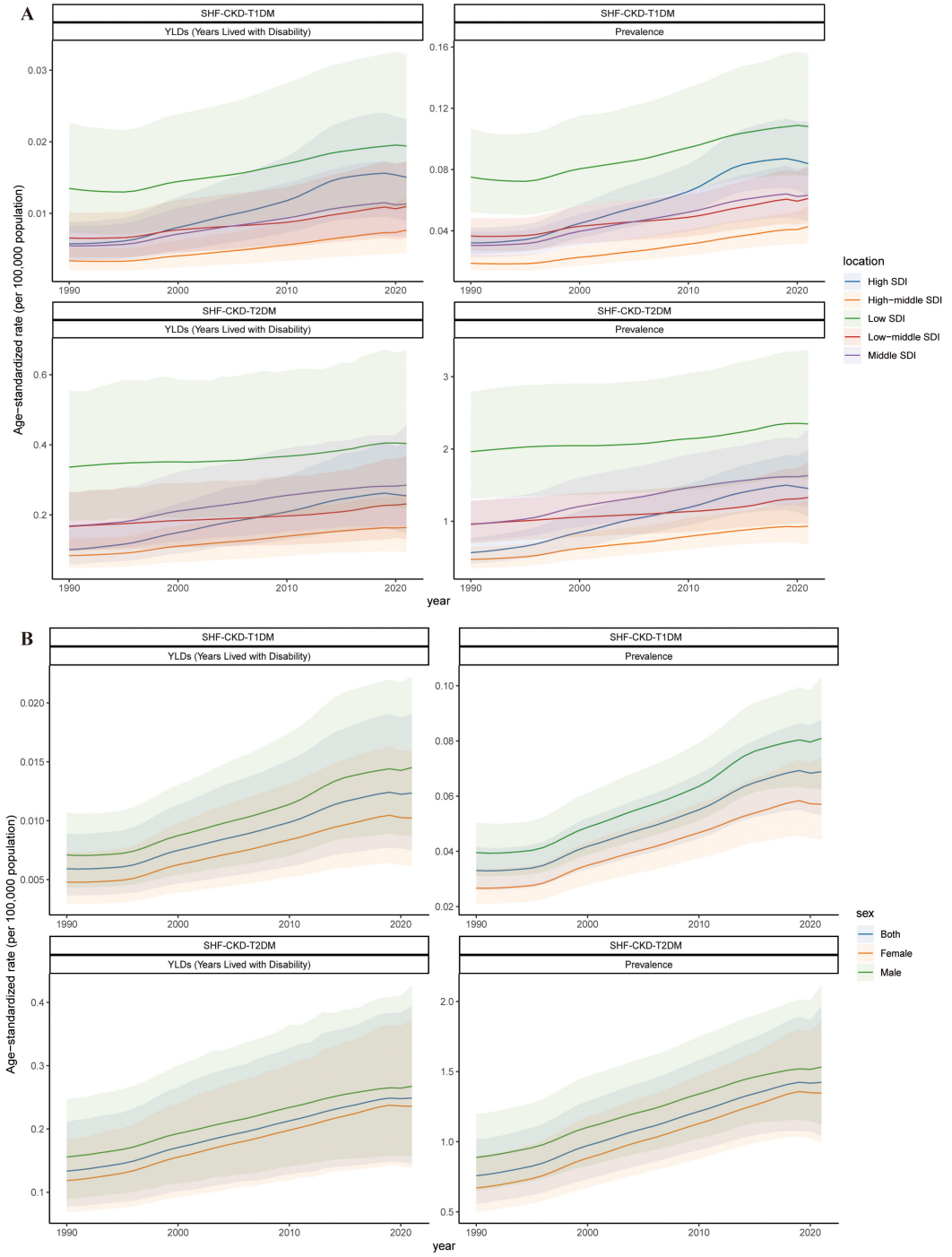

Fig. 5. Global patterns in SHF-CKD-T1/T2DM YLDs and prevalence from 1990 to 2021. (A) ASPR and ASYR across various SDIs. (B) ASPR and ASYR across various genders.

Predictive Analysis on SHF-CKD-T1/T2DM Burden to 2040

To mitigate the SHF-CKD-T1/T2DM burden, this study conducted a projection analysis for the next 19 years. Significant changes in the global SHF-CKD-T1/T2DM burden were expected between 2022 and 2040, with different trends across various indicators. The data, sourced from the GBD database, were analysed using BAPC modelling to project future trends based on the observed data. The YLDs and prevalence of SHF-CKD-T1/T2DM are projected to upward in-

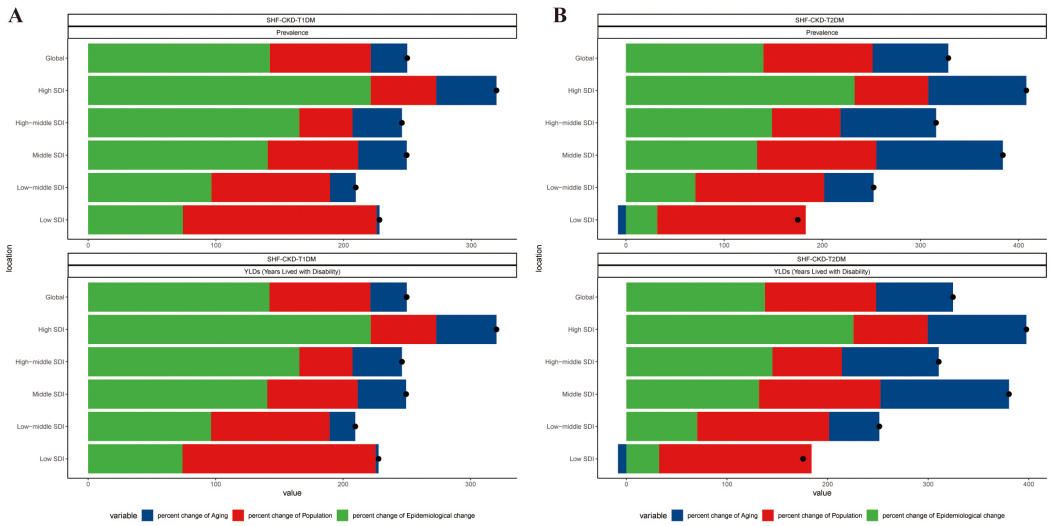

Fig. 6. Changes in YLDs and prevalence of SHF-CKD-T1/T2DM based on ageing, population growth and epidemiological change worldwide from 1990 to 2021. (A) YLDs and prevalence of SHF-CKD-T1DM. (B) YLDs and prevalence of SHF-CKD-T2DM.

creasingly, with SHF-CKD-T2DM contributing disproportionately to the overall increase. Despite this increase, YLD rates and the incidence of HF-CKD-T1/T2DM are expected to remain flatline in the future and even decrease in the female population. Furthermore, Nordpred nonparametric regression yielded similar projections. These findings underscore the need for targeted interventions and management, particularly in high-risk populations (Fig. 7).

Discussion

This study conducted a comprehensive analysis of the global, regional, and national burden of SHF-CKD-T1/T2DM from 1990 to 2021. Utilising trend analysis, decomposition analysis, inequality assessment, and predictive modelling, it revealed complex patterns of disease burden. Unlike previous research, which has largely investigated the burden of individual diseases within single countries or specific populations, our study offers the first global distribution of SHF among diabetic populations complicated by CKD. GBD 2021 data reveal that the burden of SHF-CKD-T1/T2DM continues to escalate worldwide. This study assessed the prevalence and YLDs to quantify the findings. The global disease burden continues to be predominantly influenced by SHF-CKD-T2DM, primarily due to the significantly higher number of global patients with T2DM compared to those with T1DM. However, estimated annual changes reveal more significant and variable growth rates for SHF-CKD-T1DM than for SHF-CKD-T2DM. Moreover, the EAPC analysis indicated that SHF-CKD-T1DM exhibited a higher growth rate than SHF-CKD-T2DM. This discrepancy may be attributed to factors such as recent global educational interventions targeting SHF-CKD-T2DM, improvements in public health services, advances in T1DM diagnostic techniques (such as the widespread use of antibody testing), and environmental factors, including increased rates of viral infections.

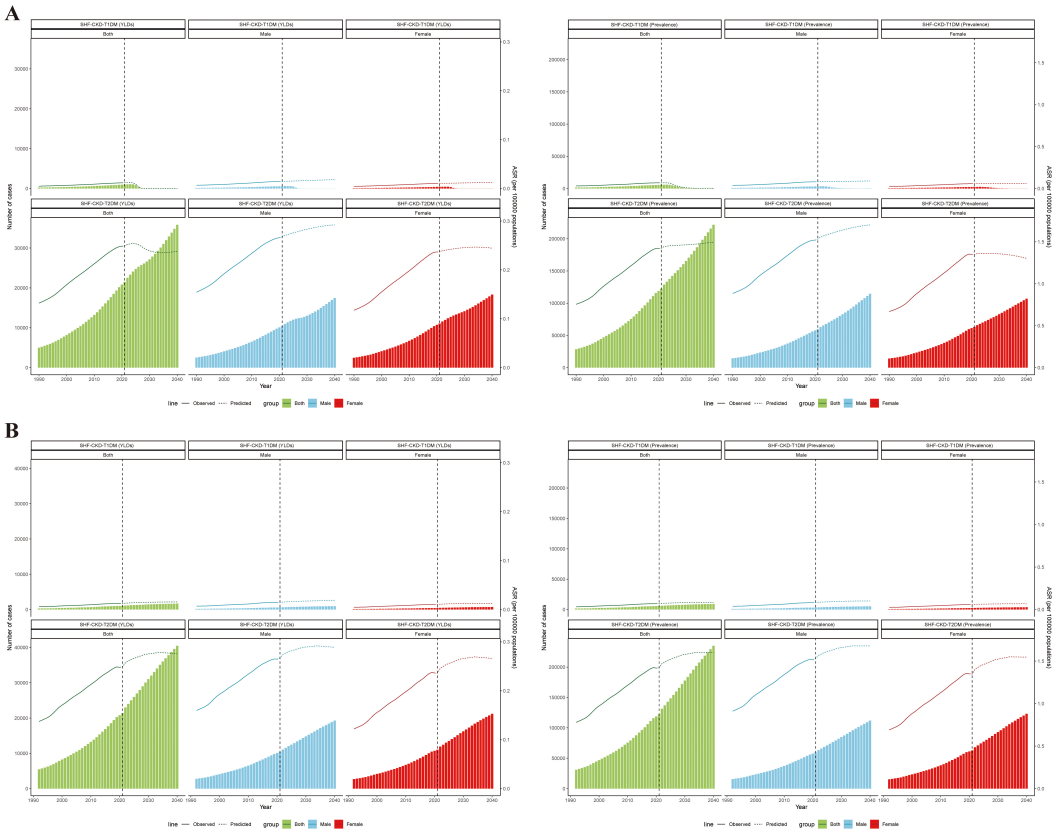

Fig. 7. Predicted trends of SHF-CKD-T1/T2DM burden to 2040. (A) The predicted case number and age-standardised rate (ASR) of prevalence and YLDs to 2040, analysed by the Bayesian Age-Period-Cohort (BAPC) model. (B) The predicted case number and ASR of prevalence and YLDs up to 2040 were analysed by the Norpred model.

Comprehensive global analyses indicate that although the disease burden associated with SHF-CKD-T1/T2DM remains higher in men than in women, EAPC analysis reveals an increasing risk among women in recent years (Basu et al, 2017). This trend may be linked to the diminished protective effects of estrogen after menopause, coinciding with a higher incidence of SHF-CKD-T1/T2DM in the postmenopausal period. Additionally, in low-SDI regions, inadequate healthcare access for women may delay diagnosis, whereas in the high-SDI regions, greater health awareness has led to increased screening. Furthermore, the larger female population in high-SDI regions is substantially larger than in low-SDI regions, contributing to a gradual rise in the overall detection rate among women (Zheng et al, 2025).

Global analysis demonstrates that the burden of SHF-CKD-T1/T2DM is predominantly concentrated in medium SDI regions, whereas ASR rates are higher in low SDI regions. This disparity can be due to large, ageing populations in medium SDI regions, contrasted with the limited healthcare resources in low SDI regions, which prevents optimal complication management (Jain et al, 2025; Shan et al, 2024). Notably, high SDI regions exhibit the highest EAPC, primarily due to dense population, superior public health services, increased disease detection rates, prompt therapeutic intervention, and reduced progression to end-stage heart failure. The regional analysis further reveals that the SHF-CKD-T1DM burden is predom-

inantly higher in Southern, Eastern, and Western Sub-Saharan Africa. In these regions, shortages of dialysis resources inhibit renal replacement therapy for T1DM patients with end-stage kidney disease (ESKD), thereby accelerating cardiorenal comorbidities (Adu, 2013). In these areas, inadequate childhood diabetes care, including poor insulin accessibility and limited blood glucose monitoring, results in early-onset proteinuria and reduced glomerular filtration, further increasing CKD and cardiovascular complications (Qu et al, 2025; Wallace et al, 2022). In contrast, the SHF-CKD-T2DM burden is highest in Western Africa and the Andean/Central Latin America. In the Andean region, such as Bolivia and Peru, obesity rates range from 30% to 40%, several times the global average (Hu et al, 2025; Singh et al, 2025). Increased obesity promotes insulin resistance and lipotoxicity, which expedites diabetic nephropathy. In parts of Western Sub-Saharan Africa, including Nigeria and Ghana, a "malnourished obesity" phenotype, characterised by abdominal fat accumulation alongside muscle atrophy, exacerbates metabolic dysfunction (Meeks et al, 2021).

Age-stratified analysis indicates that older individuals remain the high-risk demographic for SHF-CKD-T1/T2DM. Notably, the onset of SHF-CKD-T1DM occurs earlier than SHF-CKD-T2DM, potentially attributable to the distinct etiology of T1DM. T1DM onset involves a cascade of interactions between genetic predispositions (human leukocyte antigen [*HLA*]/non-*HLA* genes) and environmental factors (such as viral infections and dietary influences) that trigger immune-mediated β-cell destruction, leading to a younger average age at onset. In contrast, T2DM is predominantly influenced by lifestyle factors and age-related metabolic alterations, resulting in a later onset (Cooper et al, 2008). Intriguingly, SHF-CKD-T1DM exhibits a secondary, minor incidence peak among 10–14 years. This phenomenon may be attributed to increased detection shifting the apparent age distribution or may indicate accelerated β-cell exhaustion in pediatric T1DM patients and hormonal fluctuations during adolescence.

The decomposition analysis indicates that epidemiological factors exerted the most significant influence on the SHF-CKD-T1/T2DM burden, followed by population growth and, lastly, ageing. The paradoxical increase in the contribution of epidemiological changes may reflect improved early diagnosis and the adverse effects of certain treatment methods. While novel pharmacological interventions can decelerate CKD progression, they may also lead to complications such as ketoacidosis that increase YLD within disability-adjusted life-years (DALYs).

In the context of SHF-CKD-T1DM, population growth accounts for approximately 79% of the elevation in disease burden, likely driven by the increasing absolute number of cases and the uneven distribution of healthcare resources. Global population growth, particularly in countries with medium and low SDI, directly increases the high-risk cohort. Ageing contributes approximately 28.5% to the global increase due to cumulative disease progression and the decline in multiple organ functions. In countries with high SDI, the contribution of ageing reaches 47.32%, indicating an extended survival period in T1DM patients. In high SDI regions, such as North America and Western Europe, advancements in insulin therapy and complication management have prolonged the average lifespan of T1DM patients from

40 years to over 60 years, and extended disease duration linearly increases the risk of diabetic nephropathy. Since 1990, the prevalence of CKD in individuals over 65 has risen by 34.4%, with 38.8% of this population also experiencing hypertension, further exacerbating cardiorenal comorbidities (Yang et al, 2024).

In low SDI regions, population growth-related factors contributing to the substantial disease burden (151.44%) stem from high fertility rates and population structures. In these regions, the total fertility rate (TFR) reached 4.8, with adolescents comprising over 40% of the population. Additionally, early T1DM onset, as advanced by a 70% increase in incidence before age five, creates a vicious cycle of "young patients—early-onset kidney disease—premature death" (Zhao et al, 2025; Yang et al, 2024).

In the context of SHF-CKD-T2DM, the increasing impact of ageing in medium-sized SDI countries indicates a rapid demographic shift towards older populations. For instance, countries such as China and Mexico are experiencing significant demographic shifts, with a notable rise in the proportion of the elderly population. As of 2021, individuals aged 65 and above constituted 13.5% of China's population, with the prevalence of T2DM in this age group being 2.1 times higher than that in middle-aged adults. This situation is exacerbated by the presence of metabolic syndromes, including hypertension, which has a prevalence rate of 53.8%, and arteriosclerosis. These factors collectively create a "double-edged sword effect", where the uneven distribution of medical resources for managing glomerular hypertension and myocardial fibrosis increases disease progression.

Projections from the GBD study reveal that both YLDs and the prevalence of SHF-CKD-T1/T2DM will increase over the next 19 years, with the burden of T2DM being particularly pronounced. Ageing exacerbates the progression of diabetic nephropathy, while metabolic risk factors, such as obesity and hyperglycemia, accelerate cardiac and renal damage through lipotoxicity and microvascular lesions. The substantial burden of YLDs among females is linked to diminished estrogen's protective effects post-menopause, delayed medical intervention, and abnormal bone metabolism. In countries with a high SDI, renal failure is mitigated through urinary albumin-to-creatinine ratio (UACR) screening and the use of sodium-glucose cotransporter-2 (SGLT2) inhibitors. However, broader diagnostic criteria and treatment-related side effects, such as ketoacidosis, may paradoxically increase the reported burden. Conversely, in regions with low SDI, the natural progression of the disease persists due to rapid population growth and limited healthcare resources. Although targeted interventions like glucagon-like peptide-1 (GLP-1) receptor agonists have stabilised or improved the incidence rate among women in some areas, substantial regional disparities persist. Addressing these challenges necessitates breakthroughs in metabolic management, implementation of genetic screening, and the use of precision medicine strategies.

This study encompasses several crucial methodological considerations: Data Limitations: In resource-limited settings, under-ascertainment bias is likely to cause a systematic underestimation of the actual disease burden of SHF-CKD-T1/T2DM. Relying on secondary data from GBD 2021 also hinders the clinical phenotyping of associated comorbidities. Geospatial Resolution Constraints: Aggregating

health metrics at the national level instead of subnational levels may mask significant within-country heterogeneity, especially in large or diverse nations. Measurement Variability: Cardiovascular mortality ascertainment has inherent uncertainties, which are further exacerbated by inconsistent death certification practices. There is a potential for misclassification bias due to evolving ICD coding standards. Temporal trend detection is restricted in regions where the UI overlap exceeds 50%. Generalizability Considerations: Although this study offers novel insights into the socioeconomic determinants of SHF-CKD-T1/T2DM, caution is advised when generalizing findings to specific geopolitical contexts. This is because of variations in healthcare resource allocation patterns, chronic disease surveillance capabilities, and the infrastructure related to social determinants of health.

Using the GBD database to examine the SHF-CKD-T1/T2DM burden demonstrates considerable advantages and promising prospects. Firstly, the GBD database covers 204 countries and regions globally. Integrating multidimensional indicators, such as incidence, mortality, and YLDs, provides an accurate depiction of the spatiotemporal distribution of the disease and the heterogeneity of associated risk factors. Secondly, the GBD facilitates interdisciplinary integration. For example, machine learning analyses elucidate the synergistic pathogenic mechanisms involving hyperglycemia (contributing 80.6%), obesity (37.1%), and environmental factors (e.g., high-sodium diets) and validate the applicability of novel therapeutic approaches across regions. Future research should emphasize (1) precise prediction and dynamic monitoring, (2) stratified treatment strategies, and (3) global collaboration and policy reform, including prevention and control guidelines based on SDI quartiles. With the release of GBD 2023 data and advancements in AI algorithms, the GBD framework will be indispensable for driving precision medicine in metabolic diseases and informing public health policy decisions.

Conclusion

In conclusion, this comprehensive analysis reveals significant findings: despite advancements in global health over recent years, the absolute burden of SHF-CKD-T1/T2DM continues to rise, exhibiting substantial regional disparities and patient-related variability. GBD data provide up-to-date estimates of SHF-CKD-T1/T2DM burden by etiology, offering crucial guidance for policymakers to implement effective prevention and intervention measures at national and sub-national levels. Adopting the World Health Organisation's progressive resource-allocation model is crucial, and customised intervention strategies should be developed specifically for high-risk groups. Emphasising evidence-based policies and targeted interventions to address modifiable risk factors can help mitigate health disparities across diverse populations and foster equitable health outcomes, particularly in regions experiencing persistent socioeconomic challenges or limited healthcare access.

Key Points

- The global trends of SHF-CKD-T1/T2DM show an increasing disease burden.
- Although men show higher prevalence and YLDs (with peaks at ages 65–69 for SHF-CKD-T1DM and 70–74 for SHF-CKD-T2DM), women exhibit rapid elevations in EAPC.
- Middle SDI regions face the highest burden, driven by population growth, whereas low SDI regions bear a high burden due to poor healthcare services.
- Epidemiological changes, driven by metabolic risks, contributed 142.25% of the YLD increase to SHF-CKD-T1DM and 137.68% in SHF-CKD-T2DM.
- Projection to 2040 indicates persistent growth in SHF-CKD-T1/T2DM burden, although targeted interventions may stabilise the increase in growth rate.

Availability of Data and Materials

All data included in this study are available from the corresponding authors upon reasonable request.

Author Contributions

Conceptualisation, XW and DS; methodology, XW; software, DS; validation, XW and DS; formal analysis, XW; investigation, XW; resources, XW; data curation, XW; writing—original draft preparation, XW; writing—review and editing, DS; visualisation, XW; supervision, DS; project administration, XW. Both authors contributed to the important editorial changes in the manuscript. Both authors read and approved the final manuscript. Both authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study adhered to non-participatory research protocols with no direct engagement of human subjects or community groups. The study followed the principles outlined in the Declaration of Helsinki regarding the ethical use of de-identified, population-level data. Dissemination strategies were designed without incorporating participatory knowledge translation initiatives that involved patient advocacy organisations or community stakeholders.

Acknowledgement

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Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://www.magonlinelibrary.com/doi/suppl/10.12968/hmed.2025.0408.

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