Nephrology

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ORIGINAL ARTICLE OPEN ACCESS

Kidney Failure due to Diabetic Kidney Disease Among Australians Aged ≤45 Years, 2000–2022: A Population-Based Geospatial Analysis

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Received: 29 January 2025 | **Revised:** 25 February 2025 | **Accepted:** 2 March 2025

Keywords: diabetes | kidney failure | rural health

ABSTRACT

Aim: Evaluate the area-level incidence of kidney failure due to diabetes among Australians aged ≤45 years.

Methods: Using Australian registry and census data (2000–2022), incidence rates and prevalence of kidney failure (defined as commencing kidney replacement therapy) due to diabetes among people aged ≤45 years were compared by geographical region.

Results: Incidence (per 100 000/year, 95% confidence interval) of kidney failure due to diabetes among people aged ≤45 years in Australia was 0.72 (0.68–0.77) in 2000–2011, and 1.13 (1.07–1.18) in 2012–2022 (incidence rate ratio [IRR] 1.56, 1.50–1.62). Between 2012 and 2022, there were 48 regions where the crude incidence of kidney failure due to diabetes was more than double the national average, the highest being 49.8 cases per 100 000 per year. Between 2012 and 2022, all jurisdictions had similar age-sex-adjusted point estimates for kidney failure incidence (range 0.78–1.48) except for the Northern Territory (15.8, 13.9–17.8). The most significant characteristics associated with the rate of incident kidney failure were residence in remote areas (IRR 13.9, 13.1–14.8, ref. major cities), socioeconomic disadvantage (IRR 2.96, 2.75–3.19, ref. advantaged areas), and Aboriginal and Torres Strait Islander ethnicity (IRR 24.2, 23.0–25.5). Between the eras, people born outside Australia had the largest increase in incident cases (IRR 2.47, 2.23–2.72) but had a lower overall incidence than those born in Australia (IRR 0.55, 0.52–0.59).

Conclusion: In Australia, there was an increase in the incidence of kidney failure due to diabetes among people aged ≤45 years in the last two decades. There was a strong relationship between the risk of kidney failure and social determinants of health, including place of residence, socioeconomic status and Indigenous status.

1 | Introduction

Diabetic kidney disease is the most common cause of kidney failure in Australia, accounting for 39% of patients commencing kidney replacement therapy (KRT) between 2019 and 2022, approximately 1300 people/year [1]. While Australian incidence rates of KRT due to diabetic kidney disease have remained static since 2010 among older age groups with Type 2 diabetes mellitus (T2DM) and people with Type 1 diabetes mellitus (T1DM), a recent study demonstrated a rising incidence of KRT among younger age groups with T2DM between 2010 and 2019 among both males and females [2].

Within Australia, there is significant inequality in terms of the risk of adverse health outcomes associated with socioeconomic disadvantage and geographical remoteness, but with significant regional variability [3]. This disparity was broadly reflected in the incidence of T2DM in 2021, where outer regional areas had 1.1 times higher incidence compared to residents in a major city, and the lowest socioeconomic areas had 2.0 times higher incidence than the highest [4]. Furthermore, the incidence of T2DM among Aboriginal and Torres Strait Islander people was 2.0 times higher than among non-Indigenous Australians [4]. Aboriginal and Torres Strait Islander people are less likely to live in major cities (40.8%, compared to 59.2% living in regional/remote areas) compared to non-Indigenous Australians (73.4% living in major cities) [5].

Onset of diabetic complications is a function of disease duration and glycaemic control [6]. Serious diabetic complications (such as kidney failure) occurring in young people are uncommon and almost always preventable, or at least delayable, through early detection, improved glycaemic control, and initiating appropriate treatment. Therefore, high area-level rates of kidney failure in younger age groups may be a marker of health inequality and useful in identifying regions that may benefit from targeted public health interventions.

Given the significant regional variability in general risk of adverse health outcomes [3], this study aimed to identify areas that had high or rising rates of kidney failure due to diabetes in people ≤45 years old. To do this, we used two decades of data from the Australia and New Zealand Dialysis and Transplant Registry and Australian census data to evaluate secular trends and undertake geospatial analysis.

2 | Methods

2.1 | Study Population and Data Sources

All 2793 people who developed kidney failure due to diabetic kidney disease and commenced KRT between January 2000 and December 2022 in Australia were identified using the Australia and New Zealand Dialysis and Transplant Registry (ANZDATA). Due to the low likelihood of people aged ≤45 years with kidney failure not commencing KRT [7], KRT incidence is likely to closely reflect the incidence of kidney failure in this study.

Individual-level data obtained from ANZDATA included postcode of residence, country of birth, Indigenous status, gender, age at KRT commencement, T1DM vs. T2DM (reported to ANZDATA by treating nephrologist), smoker status (grouped as 'current', 'former' and 'never'), and the following comorbidities: coronary artery disease, cerebrovascular disease and peripheral vascular disease (reported as 'present', 'absent' or 'suspected'; in cases where comorbidity was 'suspected' it was presumed to be present).

Cases were grouped by year of KRT commencement (2000–2011 and 2012–2022), intended to correspond with the Australian censuses of 2011 and 2021. Publicly available census data from 2011 to 2021 were obtained from TableBuilder (Australian Bureau of Statistics [ABS], Canberra) to establish population denominators. In all analyses, population denominators only included people aged ≤45 years.

2.2 | Geospatial Analysis

Electronic material published in the ABS Australian Statistical Geography Standard (ASGS) was used for geospatial analysis (https://www.abs.gov.au/statistics/standards). The postcode of the usual place of residence recorded in ANZDATA was used to link individual data to statistical area (SA) and area-level variables. SAs are regions developed by the ABS for area-level statistical analysis; SA3s are designed to encompass a meaningful area relative to population centres and generally have a population of 30 000–130 000. The postcode (2016) was converted to SA3 (2021) using relevant ABS correspondence files. The postcode was not recorded for $n=17$ people, and these records were excluded. There were 19 observations where a postcode was recorded but not automatically linked to an SA, which was resolved by manual postcode search for $n=15$ ($n=4$ unresolved records were not included).

To visualise data, counts for individual SA3s were obtained and grouped by year (2000–2011 and 2012–2022). SA3 2021 shape files were imported into RStudio (Posit Software, MA, USA) and linked with case counts for SA3s as described above, as well as SA3-specific population data from the 2011 to 2021 census. Case counts for each SA3 in 2000–2011 and 2012–2022 were used to generate crude incidence rates for the population of each SA3 (≤45 years old) as cases per 100 000 population/year. Spatial autocorrelation by SA3 was evaluated using Global Moran's index to evaluate the geographical clustering of incident cases, using both frequency and incidence data. The difference in average incidence between eras was also calculated.

To supplement the analysis evaluating area-level incidence of kidney failure, the area-level prevalence of diabetes and the proportion of people with diabetes who developed kidney failure were also estimated for each SA3, considering only people aged ≤45 years. The cross-sectional prevalence of diabetes was estimated using self-reported diabetes status from the 2021 census as the numerator and the SA3 population as the denominator. The prevalence of kidney failure requiring KRT among people with diabetes was estimated for each SA3, using the incidence data from 2011 to 2022 as the numerator and diabetes status from the 2021 census as the denominator.

Choropleth maps generated using RStudio were used to visualise area-level comparisons. A table of SA3s with an incidence rate ≥2.0 per 100 000/year (2012–2022) was generated, not including regions with <10 incident cases due to increased uncertainty of estimates with such small numbers and individual privacy considerations.

2.3 | Aggregate Analysis

In addition to geospatial analyses, the incidence was compared by year on area-level variables, determined by postcode of usual place of residence: state/territory, remoteness (ABS ASGS remoteness areas) and socioeconomic status (ABS Socioeconomic

Indices for Areas 2016). The five remoteness levels are determined from the Accessibility/Remoteness Index of Australia, which is based on road distance from large population centres (https://able.adelaide.edu.au/housing-research/data-gateway/aria#methodology). For the purposes of analysis, classifications were amalgamated into major cities, regional (inner regional and outer regional) and remote (remote and very remote). Socioeconomic status was grouped based on deciles calculated from the Index of Relative Socioeconomic Advantage and Disadvantage (https://www.abs.gov.au/websitedbs/censushome.nsf/home/seifa): disadvantaged (Deciles 1–3), middle (Deciles 4–7) and advantaged (Deciles 8–10). Incidence was also compared on person-level variables: country of birth, Indigenous status, gender and age. Denominators were obtained using ABS TableBuilder, considering self-reported census data grouped by usual place of residence at the time of the 2011 or 2021 census (depending on era). Data were reported as incidence per 100 000 population/year. Direct age and sex standardisation of incidence rates to the 2011 Australian population were performed, and IRRs were calculated for these standardised rates (comparisons within each categorical variable and between eras). The standard error for standardised rates was approximated using the method of Keyfitz [8]. Otherwise, 95% confidence intervals (95% CIs) were calculated using the Clopper-Pearson exact binomial interval distribution to favour more conservative estimates. Where an IRR was unable to be determined to compare the two eras due to absent census information, a p value was estimated for counts using a chi-square test. Aggregate analysis was performed using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

2.4 | Ethical Considerations

Human research ethics approval was obtained from The University of Queensland (2023/HE002019).

3 | Results

The incidence rate per 100 000 population (95% CI) of kidney failure due to diabetes in Australians aged ≤45 years was 0.72 (0.68–0.77) between 2000 and 2011, and 1.13 (1.07–1.18) between 2012 and 2022 (IRR 1.56, 95% CI: 1.50–1.62) (Table 1).

Choropleth maps depicting incident cases of kidney failure due to diabetes and the prevalence of diabetes in Australia over the study period are presented in Figures 1 and 2. Point estimates for incidence per 100 000 population/year across the SA3s ranged from 0.0 to 20.1 (interquartile range 0.19–0.85) between 2000–2011 and 0.0–49.8 (interquartile range 0.27–1.13) between 2012 and 2022 (Figure 1). There were 48 regions where incidence was ≥2.0 cases per 100 000/year (approximately double the national average); however, 24 had <10 incident cases and were not included for further descriptive analysis (Table 2 and Figure S1). Among these regions, in general, more geographically isolated areas had higher proportions of incident KRT due to T2DM among people who developed kidney failure due to diabetes. There was significant clustering of incident cases of kidney failure due to diabetes when evaluating total frequency and incidence rates between 2000–2011 and 2012–2022, respectively (Moran's I: 0.312, $p<0.001$; 0.47, $p=0.001$; 0.48, $p=0.001$). Visual assessment demonstrated generally higher rates in SA3s outside of capital cities.

When evaluating aggregate contemporary incidence rates (2012–2022), incidence was substantially higher in the Northern Territory compared to the rest of Australia (IRR 16.2, 95% CI: 15.2–17.4), in regional (IRR 1.41, 95% CI: 1.33–1.50) and remote (IRR 13.9, 95% CI: 13.1–14.8) areas compared to major cities, in socioeconomically disadvantaged compared to advantaged areas (IRR 2.96, 95% CI: 2.75–3.19), and among Aboriginal and Torres Strait Islander people (IRR 24.2, 95% CI: 23.0–25.5).

When evaluating differences in the incidence of kidney failure between the two eras (2000–2011 and 2012–2022), almost all the groups being compared had higher rates in 2012–2022 (Table 1). Only Tasmania did not demonstrate a statistically significant increase in kidney failure incidence (IRR 0.82, 95% CI: 0.62–1.07). The group with the largest increase in incidence rates between eras was people born outside Australia (IRR 2.47, 95% CI: 2.23–2.72). Notwithstanding, this group had a lower overall risk than people born in Australia (IRR 0.55, 95% CI: 0.52–0.59). There was a statistically significant increase in the proportion of young people with incident kidney failure due to T2DM (compared to T1DM) in the contemporary era (58% vs. 53% of all incident kidney failure due to diabetes, $p=0.004$). See Table 1 for complete incidence data.

Socioeconomic status and remoteness level were compared descriptively among cases and for the total Australian population (Table S1). The most substantial differences regarding place of residence and socioeconomic status when comparing cases in this study and the Australian population (aged ≤45 years) were for people living in major cities and remote areas. In major cities, 41% of cases were from socioeconomically disadvantaged areas compared to 26% of the total Australian population living in major cities, and 17% of cases were from socioeconomically advantaged areas compared to 32% of the Australian population. In remote areas, 56% of cases were from a socioeconomically disadvantaged area compared to 52% of the total Australian population, and 2% were from a socioeconomically advantaged area compared to 7% for the Australian population.

4 | Discussion

This study demonstrated that there was an increased incidence of kidney failure due to diabetes among young Australians over time and that there was significant regional variability. In some areas, the incidence of kidney failure due to diabetes among young people was 50 times higher than the national average. Areas with the highest incidence of kidney failure tended to be outside major cities, have high rates of socioeconomic disadvantage, or a combination of both. Aboriginal and Torres Strait Islander people were considerably overrepresented among cases.

In terms of individual SA3s with a high incidence of kidney failure due to diabetes, there was significant overrepresentation of regional/remote Australia. Five metropolitan regions were also included, four of which were classified as socioeconomically disadvantaged. Interestingly, less geographically isolated

TABLE 1 | Incident cases of kidney failure due to diabetic kidney disease among people aged ≤ 45 years.

	2000 to 2011 Era				2012 to 2022 Era				
	Count (%)	Crude incidence rate	Standardised incidence rate	IRR comparing variables[a]	Count (%)	Crude incidence rate	Standardised incidence rate	IRR comparing variables[a]	IRR comparing eras[b]
Australia (total)	1157	0.72 (0.68–0.77)	—	1	1636	0.98 (0.94–1.03)	1.13 (1.07–1.18)	1	1.56 (1.50–1.62)
State/territory[c]									
NSW and ACT	258 (22)	0.48 (0.42–0.54)	0.48 (0.42–0.54)	0.67 (0.62–0.72)	376 (23)	0.67 (0.61–0.75)	0.78 (0.70–0.86)	0.80 (0.76–0.85)	1.62 (1.49–1.76)
NT	149 (13)	8.08 (6.84–9.49)	8.52 (7.15–9.89)	11.8 (10.8–12.9)	252 (15)	14.3 (12.6–16.1)	15.8 (13.9–17.8)	16.2 (15.2–17.4)	1.86 (1.68–2.06)
QLD	251 (22)	0.77 (0.67–0.87)	0.78 (0.68–0.88)	1.08 (1.01–1.16)	362 (22)	1.08 (0.97–1.19)	1.26 (1.12–1.38)	1.29 (1.21–1.36)	1.61 (1.48–1.75)
SA	77 (7)	0.68 (0.54–0.86)	0.68 (0.53–0.83)	0.95 (0.84–1.06)	92 (6)	0.84 (0.68–1.03)	0.90 (0.72–1.09)	0.93 (0.83–1.03)	1.33 (1.14–1.55)
TAS	32 (3)	0.94 (0.65–1.33)	0.97 (0.63–1.31)	1.35 (1.13–1.61)	23 (1)	0.69 (0.43–1.04)	0.79 (0.47–1.12)	0.81 (0.66–1.00)	0.82 (0.62–1.07)
VIC	210 (18)	0.53 (0.46–0.60)	0.52 (0.45–0.59)	0.72 (0.67–0.77)	287 (18)	0.67 (0.59–0.75)	0.79 (0.70–0.86)	0.81 (0.76–0.86)	1.52 (1.39–1.67)
WA	177 (15)	1.03 (0.88–1.19)	1.03 (0.88–1.18)	1.43 (1.32–1.55)	230 (14)	1.30 (1.14–1.48)	1.48 (1.29–1.67)	1.52 (1.41–0.63)	1.44 (1.30–1.59)
Remoteness level[d]									
Major cities	587 (51)	0.51 (0.47–0.55)	0.50 (0.46–0.54)	1	842 (51)	0.68 (0.63–0.72)	0.81 (0.75–0.86)	1	1.59 (1.51–1.69)
Regional	333 (29)	0.81 (0.73–0.90)	0.85 (0.76–0.94)	1.68 (1.57–1.80)	399 (24)	1.04 (0.94–1.15)	1.14 (1.02–1.25)	1.41 (1.33–1.50)	1.34 (1.25–1.45)
Remote	233 (20)	5.95 (5.21–6.77)	6.23 (5.42–7.02)	12.3 (11.4–13.3)	380 (23)	11.9 (10.7–13.1)	11.2 (10.1–12.3)	13.9 (13.1–14.8)	1.80 (1.66–1.96)
Missing	4 (< 1)	—	—	—	15 (< 1)	—	—	—	—
Socioeconomic status[e]									
Disadvantaged	469 (41)	1.03 (0.94–1.13)	1.07 (0.98–1.17)	2.55 (2.35–2.77)	666 (41)	1.99 (1.84–2.14)	1.69 (1.56–1.82)	2.96 (2.75–3.19)	1.57 (1.48–1.67)
Middle	469 (41)	0.73 (0.67–0.80)	0.73 (0.66–0.79)	1.72 (1.59–1.87)	693 (42)	1.10 (1.02–1.19)	1.19 (1.10–1.28)	2.08 (1.94–2.24)	1.64 (1.54–1.74)
Advantaged	216 (19)	0.44 (0.38–0.50)	0.42 (0.36–0.48)	1	261 (16)	0.38 (0.33–0.42)	0.57 (0.50–0.64)	1	1.36 (1.24–1.49)
Missing	3 (< 1)	—	—	—	16 (< 1)	—	—	—	—
Country of birth									
Australia	1015 (88)	0.85 (0.79–0.90)	0.97 (0.91–1.03)	1	1311 (80)	1.11 (1.05–1.17)	1.39 (1.31–1.46)	1	1.43 (1.38–1.50)
Other	142 (12)	0.35 (0.30–0.41)	0.31 (0.26–0.36)	0.32 (0.29–0.35)	314 (19)	0.65 (0.58–0.73)	0.77 (0.68–0.85)	0.55 (0.52–0.59)	2.47 (2.23–2.72)
Missing	0 (0)	—	—	—	11 (< 1)	—	—	—	—

(Continues)

TABLE 1 | (Continued)

	2000 to 2011 Era				2012 to 2022 Era				
	Count (%)	**Crude incidence rate**	**Standardised incidence rate**	**IRR comparing variables[a]**	**Count (%)**	**Crude incidence rate**	**Standardised incidence rate**	**IRR comparing variables[a]**	**IRR comparing eras[b]**
Indigenous status									
Indigenous	426 (37)	7.92 (7.18–8.71)	11.9 (10.8–13.1)	24.7 (23.3–26.3)	598 (37)	8.63 (7.96–9.35)	18.3 (16.8–19.7)	24.2 (23.0–25.5)	1.53 (1.44–1.63)
Non-Indigenous	715 (62)	0.49 (0.45–0.62)	0.48 (0.45–0.52)	1	1007 (61)	0.67 (0.63–0.71)	0.76 (0.71–0.80)	1	1.57 (1.49–1.65)
Missing	16 (1)	—	—	—	31 (2)	—	—	—	—
Sex									
Male	590 (51)	0.73 (0.67–0.79)	0.75 (0.69–0.81)	1.07 (1.01–1.14)	856 (52)	1.02 (0.96–1.09)	1.18 (1.11–1.27)	1.13 (1.08–1.19)	1.58 (1.50–1.67)
Female	567 (49)	0.71 (0.66–0.77)	0.70 (0.64–0.76)	1	780 (48)	0.94 (0.88–1.01)	1.04 (0.97–1.12)	1	1.50 (1.42–1.59)
Age[f]									
16–25 years	20 (2)	0.06 (0.03–0.09)	0.06 (0.03–0.08)	1	37 (2)	0.11 (0.08–0.15)	0.12 (0.08–0.16)	1	2.00 (1.52–2.66)
26–35 years	329 (28)	0.92 (0.83–1.03)	0.93 (0.83–1.02)	15.9 (12.6–20.0)	493 (30)	1.23 (1.12–1.34)	1.51 (1.38–1.65)	12.9 (10.9–15.3)	1.63 (1.52–1.75)
36–45 years	808 (70)	2.19 (2.05–2.35)	2.20 (2.05–2.35)	37.6 (30.0–47.2)	1106 (68)	2.93 (2.76–3.10)	3.29 (3.09–3.48)	28.0 (23.7–33.1)	1.49 (1.43–1.57)
	Count (%)				Count (%)				*p*[g]
Diabetes type[h]									
Type 1	544 (47)	—	—	—	679 (42)	109.0 (104.0–114.0)[h]	—	—	0.004
Type 2	613 (53)	—	—	—	957 (58)		—	—	
Smoker status									
Current	273 (23)	—	—	—	390 (24)	—	—	—	0.36
Former	367 (32)	—	—	—	461 (28)	—	—	—	—
Never	515 (45)	—	—	—	735 (45)	—	—	—	—
Missing	2 (<1)	—	—	—	50 (3)	—	—	—	—

(Continues)

TABLE 1 | (Continued)

	2000 to 2011 Era				2012 to 2022 Era				
	Count (%)	Crude incidence rate	Standardised incidence rate	IRR comparing variables[a]	Count (%)	Crude incidence rate	Standardised incidence rate	IRR comparing variables[a]	IRR comparing eras[b]
Macrovascular disease									
CAD	295 (25)	—	—	—	403 (25)	—	—	—	0.05
CeVD	97 (8)	—	—	—	116 (7)	—	—	—	—
PVD	383 (33)	—	—	—	444 (27)	—	—	—	—
Any	552 (48)	—	—	—	719 (44)	—	—	—	—

Note: Incident cases of kidney failure due to diabetic kidney disease among people aged ≤45 years, with kidney replacement therapy commenced between 2000 and 2022. Data reported as the number of cases (percentage of total) and the incidence rate per 100000 per year or the incidence rate ratio (IRR) (95% confidence interval [CI]). Standardised rates were standardised to age and sex based on the Australian population for 2011. When considering age or sex as the independent variable, standardisation was only performed for sex and age, respectively. IRR estimated from standardised rates. Data were grouped by Years 2000–2011 and 2012–2022, with population denominators determined from the 2011 and 2021 census, respectively (— indicates no suitable population data available for comparison).

Abbreviations: CAD, coronary artery disease; CeVD, cerebrovascular disease; PVD, peripheral vascular disease.

[a]IRR (95% CI), where the comparison of interest is the difference between individual explanatory variables.

[b]IRR (95% CI), where the comparison of interest is the difference between eras, considering the 2000–2011 era as the referent.

[c]ACT, Australian Capital Territory; NSW, New South Wales; NT, Northern Territory; QLD, Queensland; SA, South Australia; TAS, Tasmania; VIC, Victoria; WA, Western Australia. The sum of cases is less than the Australian total, which reflects cases from other Australian territories. The IRR ([a]) estimated considering total Australian incidence as the reference group.

[d]Remoteness level grouped as Major City, Regional (Outer and Inner Regional) and Remote (Remote and Very Remote).

[e]Socioeconomic status determined from the Index of Relative Socioeconomic Advantage and Disadvantage (grouped as Disadvantaged: Deciles 1–3; Middle: Deciles 4–7; and Advantaged: Deciles 8–10). Socioeconomic Indices for Areas, Australian Bureau of Statistics.

[f]The youngest age group only included those aged ≥16 years, as there were no incident cases of kidney failure due to diabetes among people aged 15 years or younger.

[g]Where census data were unavailable to generate an IRR comparing the two eras, a *p* value comparing the two eras was estimated using a chi-square test. Diabetes type: Type 1 vs. Type 2. Smoker status: current/former vs. never. Macrovascular disease: any vs. none reported.

[h]Incidence determined for both Type 1 and Type 2 diabetes using census data. Denominator data were only available for the 2021 census.

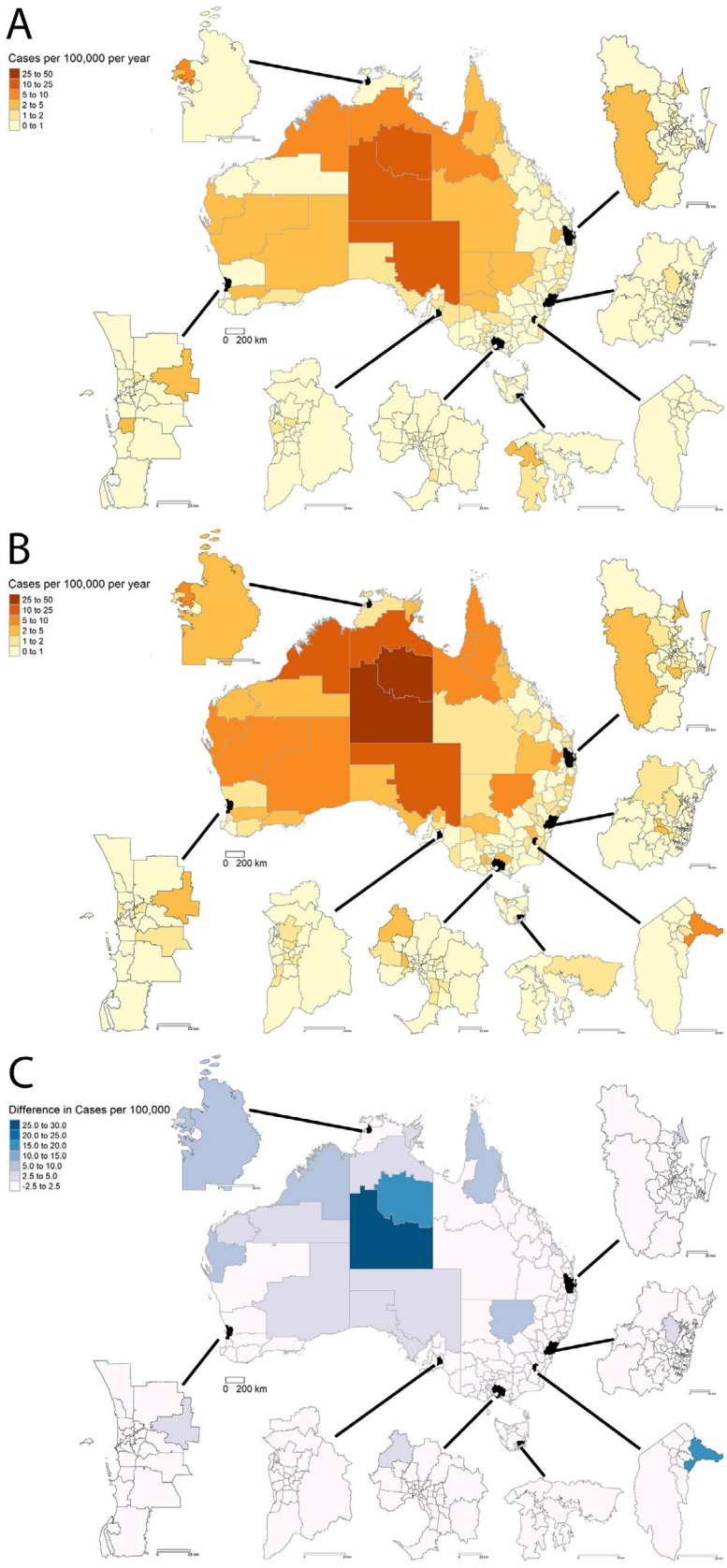

FIGURE 1 | Incidence of kidney failure. Crude incidence rates of kidney failure due to diabetes among people aged ≤45 years (cases per 100000 population/year) by SA3. (A) 2000–2011; (B) 2012–2022. (C) Difference in incidence rate between eras. Capital cities (indicated in black) expanded with greater magnification. Large scale bar = 200 km; smaller scale bars = 25 km.

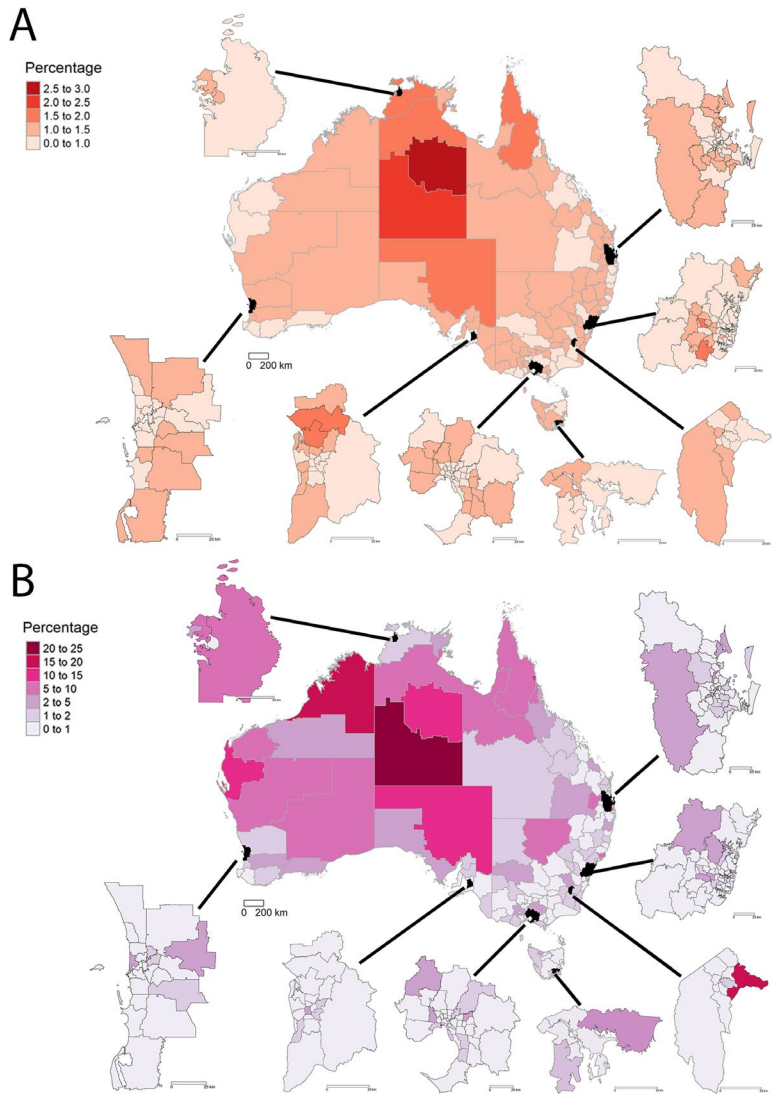

FIGURE 2 | Prevalence of diabetes and kidney failure due to diabetes. (A) Estimated prevalence (%) of diabetes per SA3 among people aged ≤45 years, based on 2021 census data (self-reported). (B) Estimated prevalence (%) of kidney failure due to diabetes among people with diabetes, using total incidence cases of kidney failure between 2012 and 2022 as the numerator and the total number of people with diabetes per SA3 as the denominator. Capital cities (indicated in black) expanded with greater magnification. Large scale bar = 200 km; smaller scale bars = 25 km.

regions had higher proportions of kidney failure due to T1DM compared to remote areas, where incident cases of kidney failure were predominantly due to T2DM. Reasons for this could include a higher likelihood of people with T1DM moving to less geographically isolated regions [9], higher incidence of T1DM in less geographically isolated regions [10], or higher rates of complications of T1DM leading to premature death in more geographically isolated regions [11]. When compared to another recent Australian study of all-cause kidney failure hotspots in Australian capital cities, of 19 SA3s identified with high kidney failure incidence, only Mount Druitt (Sydney) and Brimbank (Melbourne) were on both lists [12]. This could suggest an interaction between age-specific incidence, place of residence, and socioeconomic status, which complicates the prediction of future health service demand by area. It could be hypothesised that areas with substantial young-onset kidney failure due to diabetes may be more likely to have higher numbers of incident cases of kidney failure in the future compared to regions where incident KRT is predominantly among older people, especially if antecedent and potentially causal social determinants of health are not addressed. These could include access to primary care [13], access to medications [14], differences in education levels and health literacy [15, 16], and access to healthy food [17].

In many remote areas, the incidence rate of kidney failure due to diabetes was substantially higher than the Australian average, and the proportion of people with diabetes who developed kidney failure due to diabetes was as high as 23% (Table 2). A higher prevalence of kidney failure among people with diabetes was usually associated with a higher self-reported prevalence of diabetes (Figure 2), which is probably a consequence of poor diabetic control. However, this could be a sign of diabetes underdiagnosis, where people present late and are only diagnosed with diabetes in the presence of end-organ damage. In this scenario, the diabetes prevalence based on self-reporting may be underestimated. This inference was supported by a study of 51 remote communities in the Northern Territory, where 14%–20% of people with diabetes had an HbA1c of >10%, and diabetes

TABLE 2 | Regions with high incidence rates of kidney failure due to diabetes among people aged 45 years or younger.

SA3 name	SA3 code	State/ territory	Socioeconomic status[a]	Remoteness classification	Population (aged ≤45 years)[b]	Diabetes prevalence[c]	Incident cases (% of DM)[d]	Percent T2DM[e]	Incidence rate (IR) (95% CI)[f]	Absolute change in IR[g]
Alice Springs	70201	NT	Middle	Remote	25352	608 (2.4)	139 (23)	97%	49.8 (41.9–58.8)	29.74
Barkly	70202	NT	Disadvantaged	Very remote	3789	110 (2.9)	14 (13)	92%	33.6 (18.4–56.3)	15.91
Kimberley	51001	WA	Disadvantaged	Very remote	24389	301 (1.2)	52 (17)	98%	19.4 (14.5–25.4)	9.39
Outback–North and East	40602	SA	Disadvantaged	Very remote	15465	271 (1.8)	30 (11)	97%	17.6 (11.9–25.2)	3.42
Katherine	70205	NT	Disadvantaged	Remote	13586	257 (1.9)	18 (7.0)	94%	12.0 (7.1–19.0)	4.02
Outback–North	31502	QLD	Disadvantaged	Very remote	20767	275 (1.3)	21 (7.6)	95%	9.2 (5.7–14.0)	2.50
Far North	31501	QLD	Disadvantaged	Very remote	21493	339 (1.6)	21 (6.2)	100%	8.9 (5.5–11.9)	5.33
Darwin Suburbs	70102	NT	Middle	Outer regional	36305	378 (1.0)	34 (9.0)	97%	8.5 (5.9–11.9)	1.19
Bourke–Cobar–Coonamble	10501	NSW	Disadvantaged	Very remote	11910	145 (1.2)	10 (6.9)	80%	7.6 (3.7–14.0)	5.42
Goldfields	51103	WA	Middle	Very remote	25332	283 (1.1)	21 (7.4)	90%	7.5 (4.7–11.5)	3.17
Darling Downs–East	30702	QLD	Disadvantaged	Inner regional	23109	264 (1.1)	14 (5.3)	29%	5.5 (3.0–9.2)	2.36
Mid West	51104	WA	Disadvantaged	Very remote	29824	351 (1.2)	18 (5.1)	100%	5.5 (3.3–8.7)	2.45
East Pilbara	51002	WA	Middle	Very remote	18725	205 (1.1)	10 (4.9)	100%	4.9 (2.3–8.9)	—
Cairns–North	30601	QLD	Middle	Outer regional	32969	219 (0.7)	17 (7.8)	100%	4.7 (2.7–7.5)	−2.42
West Pilbara	51003	WA	Advantaged	Remote	22290	196 (0.9)	11 (5.6)	91%	4.5 (2.2–8.0)	—
Tablelands (East)–Kuranda	30605	QLD	Disadvantaged	Outer regional	20801	187 (0.9)	10 (5.3)	70%	4.4 (2.1–8.0)	2.34
Eyre Peninsula and South West	40601	SA	Disadvantaged	Remote	30231	382 (1.3)	14 (3.7)	57%	4.2 (2.3–7.1)	2.70
Gold Coast–North	30903	QLD	Middle	Major cities	32907	260 (0.8)	15 (5.8)	33%	4.1 (2.3–6.8)	3.12
Gladstone	30805	QLD	Disadvantaged	Inner regional	37801	400 (1.1)	12 (3.0)	17%	2.9 (1.5–5.0)	—
Ipswich Hinterland	31002	QLD	Disadvantaged	Inner regional	35981	420 (1.2)	10 (2.4)	50%	2.5 (1.2–4.6)	0.01
Brimbank	21301	VIC	Disadvantaged	Major cities	113331	1212 (1.1)	28 (2.3)	32%	2.2 (1.5–3.2)	1.30
Browns Plains	31103	QLD	Disadvantaged	Major cities	63684	827 (1.3)	15 (1.8)	60%	2.1 (1.2–3.5)	1.32

(Continues)

TABLE 2 | (Continued)

SA3 name	SA3 code	State/ territory	Socioeconomic status[a]	Remoteness classification	Population (aged ≤ 45 years)[b]	Diabetes prevalence[c]	Incident cases (% of DM)[d]	Percent T2DM[e]	Incidence rate (IR) (95% CI)[f]	Absolute change in IR[g]
Fairfield	12702	NSW	Disadvantaged	Major cities	112695	1071 (1.0)	25 (2.3)	72%	2.0 (1.3–3.0)	1.27
Mount Druitt	11603	NSW	Disadvantaged	Major cities	77245	1335 (1.7)	17 (1.3)	53%	2.0 (1.2–3.2)	1.43

Note: Incidence of kidney failure by Australian Bureau of Statistics defined regions (statistical area 3 [SA3]), presented in descending order. Map demonstrating the location of each SA3 is available in Figure S1 (— indicates no comparison could be made due to changes in geographical boundaries over time).

[a]Index or Relative Socioeconomic Advantage and Disadvantage, determined from the most representative decile of the total resident population (Disadvantaged [Deciles 1–3], Middle [Deciles 4–7] and Advantaged [Deciles 8–10]).

[b]Total population of SA3 aged ≤ 45 years.

[c]Number of people aged ≤ 45 years with diabetes (self-reported in 2021 census), and percentage of the SA3 population aged ≤ 45 years with diabetes.

[d]Number of incident cases of kidney failure due to diabetes between 2012 and 2022, and estimated percentage of people with diabetes (DM) who have kidney failure due to their diabetes within the SA3.

[e]Percentage of incident cases of kidney failure due to Type 2 diabetes mellitus (T2DM) between 2012 and 2022.

[f]Crude incidence rate (cases per 100 000 population per year) of kidney failure due to diabetes among people aged ≤ 45 years within the SA3 between 2012 and 2022, with a 95% confidence interval (CI).

[g]Absolute change in crude incidence rate between 2000–2011 and 2012–2022 (positive values represent increased incidence between eras).

prevalence was substantially higher than the self-reported census figures would suggest (ranging from 0.8% to 2% in the 10- to 19-year-old age group to 16%–25% in the 30- to 39-year-old age group) [18]. Another recent study in Western Australia across six remote communities found that 6% of adults had undiagnosed T2DM [19].

Socioeconomic disadvantage is a known risk factor for both kidney failure and T2DM [20]. An Australian study considering all age groups (2000–2009) demonstrated a similar IRR for the risk of kidney failure due to diabetic kidney disease in the most disadvantaged compared to the most advantaged decile (IRR 2.38, 95% CI: 2.09–2.71), similar to data from the same timeframe in the present study (IRR 2.55, 95% CI: 2.35–2.77) [20]. While socioeconomic disadvantage and regional/remote place of residence frequently co-occur, 28% of cases who lived in major cities were from areas classified as socioeconomically disadvantaged, compared to just 18% of people aged ≤45 years living in major cities Australia-wide, suggesting an independent association between socioeconomic status and kidney failure in this study.

Young Aboriginal and Torres Strait Islander people had a significantly higher incidence of kidney failure due to diabetes than people who did not identify as Indigenous. This is reflective of the known significant gap in health outcomes experienced by Aboriginal and Torres Strait Islander people [21]. Strategies to provide tailored, community specific and culturally appropriate care in collaboration with communities can effectively improve health outcomes in this vulnerable group, particularly in geographically isolated regions [22, 23]. In Queensland, mortality due to endocrine/metabolic disorders among Aboriginal and Torres Strait Islander people reduced by 43.3% in 2015–2017 compared to 2002–2004, which has been attributed to public health interventions as part of the 'Closing the Gap' initiative [24]. While the incidence of kidney failure among Aboriginal and Torres Strait Islander people had increased over time, change in incidence was proportional to that among non-Indigenous Australians.

Of the groups evaluated in this study, people born outside Australia had the largest rise in the incidence of kidney failure due to diabetes over time. While the incidence rate remained lower than that of people born in Australia, this is probably reflective of the heterogeneity of this group and suggestive that people born in some countries are at higher risk than others. A recent Australian study demonstrated that people born outside of Australia experienced more difficulty navigating and engaging with healthcare systems, which was more significant among non-English speakers [25]. Between 2011 and 2019, incidence rates of T2DM in Australia decreased among people born in Australia and other English-speaking countries. However, incidence rates increased for people born in Asia, North Africa, the Middle East and the Pacific Islands [26]. Higher incidence of kidney failure due to diabetes was also seen in these groups in an Australian study evaluating KRT incidence data from 1993 to 2001 [27].

When evaluating spatial autocorrelation results, Moran's index was persistently positive when evaluating both absolute counts and incidence rates. This indicates a significant clustering of incident cases within related SA3s instead of a random

geographical distribution. This provides further support to our interpretation of results based on aggregate area-based indices such as socioeconomic status and geographical remoteness. It also adds robustness to the interpretation of incidence rates in SA3s with smaller populations, where it could be inferred that while some of the higher rates may not be as accurate as those from more densely populated SA3s, they could be indicative of wider regional trends.

This study is the first in Australia to evaluate regional variability of incident kidney failure due to diabetes among young people. Its strengths lie in the population-based sampling strategy, where it is expected that most incident cases of kidney failure would be captured. Limitations are related to area-level findings due to small numbers within SA3s, which are a consequence of lower population densities in regional and remote areas. Using the postcode of usual place of residence at the commencement of KRT may also be suboptimal, as it does not allow for changes in residence over time and may not accurately reflect actual place of residence in peripatetic contexts. While there is a degree of uncertainty related to smaller numbers, many of the regions we have identified as having poorer outcomes also share risk factors for poor outcomes based on aggregate analysis. Ultimately, this is likely to be of public health significance.

The study was also limited by the way diabetic kidney disease was classified as the primary cause of kidney failure. While this was based on clinical assessment by the treating nephrologist, there is potential for misclassification as kidney biopsies are less likely to be performed in Australia in people with diabetes and features of kidney disease [28]. In a 2014 literature review, the percentage of non-diabetic kidney disease among people with diabetes and kidney disease ranged from 7.8% to 72.5% [29], and in an Australian retrospective study of kidney biopsy results, dual pathology on biopsy was significantly more common among Indigenous (range 9.7%–20.2%) compared to non-Indigenous (5.6%) Australians ($p = 0.009$) [30]. It is therefore possible that some cases of kidney failure due to diabetic kidney disease were due to, or in the setting of, alternate pathology, and it is plausible that the likelihood of misclassification may be higher in non-metropolitan centres due to resource limitations with respect to accessing kidney biopsy. This study did not account for unmeasured confounders such as genetic susceptibility to diabetic kidney disease.

5 | Conclusions

Our study has demonstrated a higher incidence of kidney failure due to diabetes among young people over time, with significant geographical variability. Among regions with the highest incidence rates, there was an overrepresentation of geographical isolation and socioeconomic disadvantage. Diabetic complications in young people are, for the most part, preventable, with good evidence that primary and secondary prevention strategies reduce diabetic complications and premature mortality [31, 32]. By highlighting regions with disproportionately high incidence of kidney failure due to diabetes, it is possible that targeted community-level intervention could be undertaken to try to improve preventative measures and early intervention.

Acknowledgements

Some of the data reported here have been supplied by the Australia and New Zealand Dialysis and Transplant Registry (ANZDATA). The interpretation and reporting of these data are the responsibility of the authors and should not be seen as an official policy or interpretation of ANZDATA. Open access publishing facilitated by The University of Queensland, as part of the Wiley - The University of Queensland agreement via the Council of Australian University Librarians.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.