



Time to integrate climate science into kidney care planning: a 'PASIGE' to a climate change mitigation and adaptation framework

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Purpose of review

Kidney diseases affect around 850 million people globally and are a growing public health burden, with high rates of associated cardiovascular mortality and no major decline in age-standardized mortality compared to other noncommunicable diseases. Climate change is an inequitable driver of kidney diseases, and climate-related disasters can disrupt access to life-sustaining kidney replacement therapies. Conversely, the care of patients with kidney diseases contributes to greenhouse gas emissions, pollution, and generates large amounts of waste.

Recent findings

Environmentally sustainable kidney care planning is pursuing kidney care practices and innovations that minimize environmental harm while remaining patient-centered and cost-effective. An adaptation and mitigation framework (a structured approach to developing adaptation strategies, policies, and measures) to guide this is lacking.

Summary

We propose the 'PASIGE' framework to guide climate science integration in kidney care planning -> Prevent: approaches to prevent kidney disease, its progression to kidney failure, and complications; Adopt: sustainable lifestyle, practices and therapies; Screen: targeted population screening for early detection and identification of kidney disease; Innovate: technology, manufacturing, procurement, energy sources and transportation; Generate: sustainably powered and produced low-impact net zero waste kidney replacement therapies resilient to climate threats; and Enhance: patient engagement, care quality, and system resiliency.

Keywords

adaptation, climate change, disaster management, disaster preparedness, disaster recovery, disaster response, framework method, frameworks, mitigation, nephrology, sustainable kidney care

INTRODUCTION

The estimated global prevalence of kidney diseases is tremendous and rising [1,2]. They affect about 9.5% of the population globally, equating to approximately 850 million people [3]. The Global Health Data Exchange tool reports that in 2019, kidney diseases were estimated to result in 1.43 million deaths, and an additional 1.73 million deaths from cardiovascular diseases were attributable to impaired kidney function [4]. The presence of chronic kidney disease (CKD) increases the risk of 10-year cardiovascular disease mortality three to five-fold in people with diabetes compared to diabetes alone [5]. While the global age-standardised mortality rate for several noncommunicable diseases is declining, a similar decline was not seen for CKD [6]. Forecasting models estimate that in 2040, kidney diseases will be the fifth leading cause of years of life lost [7].

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KEY POINTS

- Chronic kidney disease affects around 850 million people globally and is a growing public health burden.
- Climate change is both a driver and a consequence of kidney disease, and climate-related disasters disrupt access to kidney replacement therapies.
- Introducing a sustainability lens to kidney care planning is being actively called upon, and climate science can inform approaches to accomplish this.
- We propose a novel adaptation and mitigation framework to integrate climate science into delivering environmentally sustainable kidney care.

Recognizing the significant public health burden of CKD, the WHO adopted a landmark resolution at the 78th World Health Assembly in May 2025, following sustained advocacy by the International Society of Nephrology, committing to reduce the burden of noncommunicable diseases by promoting kidney health and strengthening the prevention and control of kidney disease. In this review, we argue that incorporating climate science is essential to fully address the complex and evolving burden of CKD, acute kidney injury (AKI), and end-stage kidney disease (ESKD) globally and propose a framework for how to accomplish this.

THE INTERCONNECTEDNESS OF CLIMATE CHANGE, KIDNEY HEALTH, AND KIDNEY CARE

The United Nations defines climate change as the long-term shifts in temperatures and weather patterns [8]. While these shifts can be natural, since the 1800s, human activities, primarily due to burning fossil fuels, have been the main driver. In addition, pollution, the unwanted waste of human origin released into the air, land, water, and ocean, is also recognized to be a key environmental and global threat [9]. Air pollution and climate change are entwined because the emissions driving both come largely from fossil fuel or biofuel burning [9].

Climate change negatively affects human health due to a complex interplay of rising average temperatures and increased exposure to extreme events, infectious disease transmission, and altered rainfall patterns affecting food and water supply [10,11]. Thus, climate change, kidney health, and kidney care are interconnected (Fig. 1).

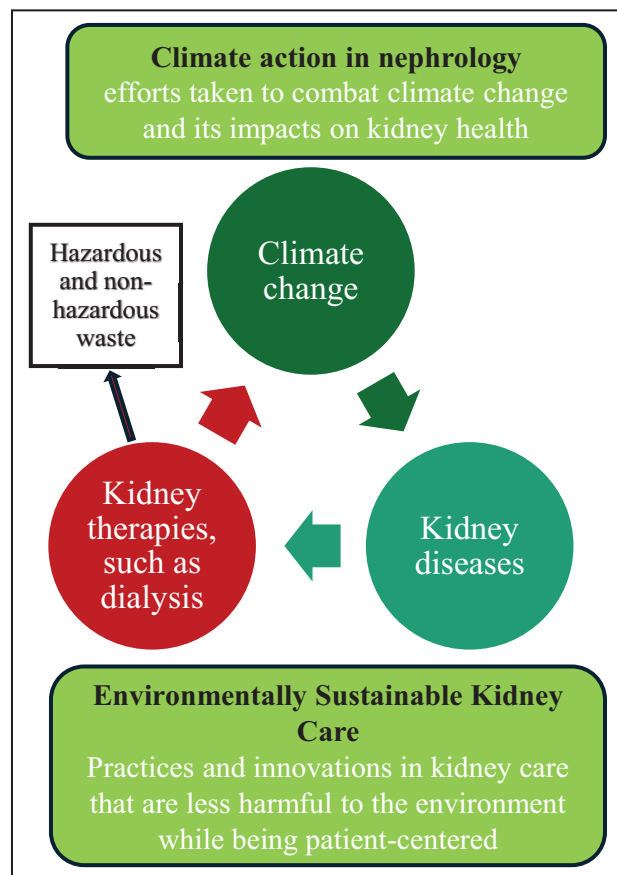


FIGURE 1. The interconnectedness of climate change, kidney health, and kidney care.

Climate change as an inequitable driver of chronic kidney disease, acute kidney injury, and end-stage kidney disease

CC is linked to a higher incidence of heat-related AKI and CKD, nephrolithiasis, and vector-borne kidney diseases [12–17]. Heat stress nephropathy, a chronic tubulointerstitial disease, is believed to be a consequence of global warming and an increase in extreme heatwaves [18]. Furthermore, as outlined by the Joint Commission from the Lancet and the University College of London, major threats to global health from climate change are also manifested through water and food insecurity, air pollution, extreme climatic events, and population displacement [19,20]. These can contribute to the increased risk of kidney disease as well. For example, increased exposure to fine particulate matter and other air pollutants increases the risk of incident CKD, some glomerulonephritides, and progression to ESKD [21–23]. Also, climate change and biodiversity loss have important implications for vector-borne diseases, such as malaria and dengue, through their effects on pathogens, vectors, and hosts, and the ability of health systems to prevent and treat these diseases

[24]. AKI is one of the most severe complications of these vector-borne infections and is associated with a higher risk of mortality [25].

Climate-sensitive kidney risks will disproportionately impact people in lower and middle-income countries and the most vulnerable and disadvantaged individuals, such as women, children, ethnic minorities, poor communities, migrants or displaced persons, and older populations [26]. In high-income countries, the burden of kidney disease and kidney failure is disproportionately higher in disadvantaged and ethnic populations [27–30]. Poverty increases vulnerability to climate change by exacerbating exposure and decreasing adaptive capacity [31,32]. Thus, climate change is an important social determinant of health and an inequitable driver of kidney diseases.

Kidney care contributing to climate change

Conversely, kidney care contributes to greenhouse gas emissions and generates a tremendous quantity of waste. About 2.8 million people globally are receiving dialysis [33], a resource-intensive therapy. Each haemodialysis session requires 12.0–19.6 kWh of electricity consumption and generates 2.5–8 kg of hazardous waste [12,34–36]. The global water use of haemodialysis is approximately 265 million m³/year [37]. Dialysis alone leads to 3.8–10.2 tCO₂-eq emissions per patient annually [35,38]. The environmental burden attributed to peritoneal dialysis and transplantation, although lower, is significant as well. The yearly atmospheric carbon dioxide equivalent (CO₂e) emissions from automated peritoneal dialysis were estimated to be 1420 kg for APD and 684 kg for continuous ambulatory peritoneal dialysis per patient [39]. Progress to address this has been minimal as health systems tend to prioritize affordability over sustainability in lower-resourced settings where improving access to kidney care is a top priority [40]. Policy inertia, capitalistic tendencies, lack of regulatory frameworks, and lower prioritization tend to result in a ‘business-as-usual’ approach [41].

Climate change impacting kidney care

CC-related disasters can directly impact kidney patients, particularly those receiving dialysis [42–45]. The provision of dialysis requires the availability of equipment, electricity, clean water, and trained personnel, all of which may be disrupted in a disaster. Indeed, postdisaster analyses report an increased risk of hospitalizations and mortality among dialysis patients [46–48]. Certain disasters, such as earthquakes, can also lead to AKI [49,50].

A CONCEPTUAL UNDERSTANDING OF KIDNEY CARE PLANNING AND CLIMATE SCIENCE

Kidney care planning

Care planning is the “process by which healthcare professionals and patients discuss, agree and review an action plan to achieve the goals or behaviour change of most relevance and concern to the patient” [51]. The emphasis is placed on delivering patient-centred care and accounting for their condition, and unique circumstances, attitudes, and preferences in developing an effective care plan [51]. In kidney care, care planning also varies by the stage of the kidney disease, and other factors might play a role, such as access to and availability of therapies [52,53]. Nevertheless, a conceptual overview of recommended approaches to kidney care planning as per leading organizations in nephrology is presented in Table 1.

Climate science

Traditionally, climate science is regarded as a field that employs theoretical knowledge and mathematical modelling to explain and predict the global climate system, enabling simulations of atmospheric and oceanic processes that influence key climate variables, such as temperature and rainfall [53]. However, the Intergovernmental Panel on Climate Change (IPCC) broadens the scope of climate science to integrate scientific, technical, and socio-economic knowledge on climate change, its impacts, future risks, key indicators, and the full range of mitigation and adaptation options [54].

INTEGRATING CLIMATE SCIENCE INTO (ENVIRONMENTALLY SUSTAINABLE) KIDNEY CARE PLANNING

Given the interconnected relationship between climate change and kidney health, as well as the rising burden of kidney diseases, championing sustainability in kidney care planning is a timely and critical matter. We contend that climate science leverages interdisciplinary approaches linking natural, social, and health sciences to improve kidney health and patient care. Integrating climate science can help advance the mechanistic understanding of kidney diseases, associated risks, develop strategies to address them, promote sustainable practices, increase resiliency, and ultimately generate data and evidence to inform clinical practice and policy to inform kidney care planning. Also, monitoring kidney health can serve as an early-detection system for environmental insults and for measuring and monitoring climate-sensitive health risks [55]. As

Table 1. Traditional elements of kidney care planning and how a climate change adaptation and mitigation framework (PASIGE) presented in Fig. 2 can be applied to deliver environmentally sustainable kidney care [51–53]

General population at high risk (including environmental risks) -> Screen

- Early identification of kidney disease

People with AKI or AKD -> Prevent, Adopt

- Identify people at high risk of recurrent AKIs
- Educate to minimize the risk of recurrent AKIs
- Implement cardiovascular risk management

CKD Stage 1-2-3a -> Prevent, Adopt, Enhance

- Identify people at high risk of progression to ESKD/developing cardiovascular complications
- Initiate (if applicable):
 - Disease-modifying therapies (polycystic kidney disease, glomerulonephritis, etc.)
 - Risk-modifying therapies (SGLT2i, RAASi, MRAs)
- Implement cardiovascular risk management

CKD Stage 3b -> Prevent, Adopt, Enhance

- Approaches for prevention and management of complications
- Initiate (if applicable):
 - Risk-modifying therapies (SGLT2i, RAASi, MRAs)
 - Consider disease-modifying therapies (polycystic kidney disease, glomerulonephritis, etc.)
- Implement cardiovascular risk management
- Educate and promote self-efficacy and self-management

CKD Stage 4 -> Prevent, Adopt, Enhance

- Initiate approaches for the prevention and management of complications
- Discuss and prepare for kidney replacement therapies
- Prioritize:
 - Preemptive living donor kidney transplantation
 - Home dialysis therapies
- Offer conservative kidney management, if appropriate
- Implement cardiovascular risk management
- Educate and promote self-efficacy and self-management

CKD Stage 5-ESKD -> Prevent, Adopt, Innovate, Generate, Enhance

- Initiate approaches for the prevention and management of complications
- Prioritize:
 - Living donor kidney transplantation
 - Deceased donor kidney transplantation
 - Home dialysis therapies
- Offer:
 - Conservative kidney management, if appropriate
 - Advanced care planning
- Educate and promote self-efficacy and self-management
- Promote environmentally sustainable practices in dialysis

AKD, acute kidney disease; AKI, acute kidney injury; CKD, chronic kidney disease; ESKD, end-stage kidney disease; MRA, mineralocorticoid receptor antagonist; RASi, renin-angiotensin system inhibitors; SGLT2i, Sodium-glucose cotransporter 2.

an example, longitudinal kidney function data and its monitoring in high-risk regions, such as urban and industrial zones, can be an early indicator of the cumulative toll of polluted air on population health. Several

renal biomarkers of glomerular or tubular injury can help map environmental toxic exposure patterns that may have implications for other diseases as well.

Endorsed by the “GREEN-K” initiative of the International Society of Nephrology and several other organisations globally [41,56,57], environmentally sustainable kidney care (ESKC) entails pursuing kidney care practices and innovations that minimize environmental harm while remaining patient-centred and cost-effective [41,58[□]]. However, a systematic approach to operationalize this is lacking. There are several gaps in the knowledge and practices of kidney care professionals and patients [59,60[□],61[■]]. Climate literacy, research, and innovation targeting the development of newer technologies and treatment methods that are both effective and eco-friendly can significantly improve kidney care planning through a sustainability lens [40[□],62[□]]. We propose a climate change adaptation and mitigation framework, a structured approach to developing adaptation strategies, policies, and measures [63], to guide the integration of climate science into ESKC planning. We now present the ‘PASIGE’ framework (Fig. 2).

Prevent

Prevention covers the spectrum of stages highlighted in Table 1: preventing AKI, AKD, and recurrent AKI in high-risk populations; preventing CKD and CKD progression to ESKD; and reducing cardiovascular morbidity and mortality through effective cardiovascular risk management in patients at all stages of kidney disease. These goals are fundamental to kidney care planning and form the core principles of ESKC. The relationship between climate change and unhealthy food systems is well documented in contributing to the susceptibility to noncommunicable diseases such as type 2 diabetes and obesity, which are major risk factors for CKD. In this context, multi-level policy reforms and large-scale public health strategies, informed by climate science, can enable the implementation of targeted prevention measures.

Furthermore, the role of environmental factors in explaining the pathophysiology of CKD and how climate change is implicated in CKD incidence and progression, as well as risk factors, can provide critical insights into the prevention of CKD. In a study from Iran, proximity of residence to mines, mobile antennas, and exposure to pesticides and industrial chemicals were significantly associated with a higher risk of CKD [64]. The role of environmental factors and heavy metals, chemicals, and pollutants has been proposed in the cause of CKD [65,66]. An increase in particulate matter exposure

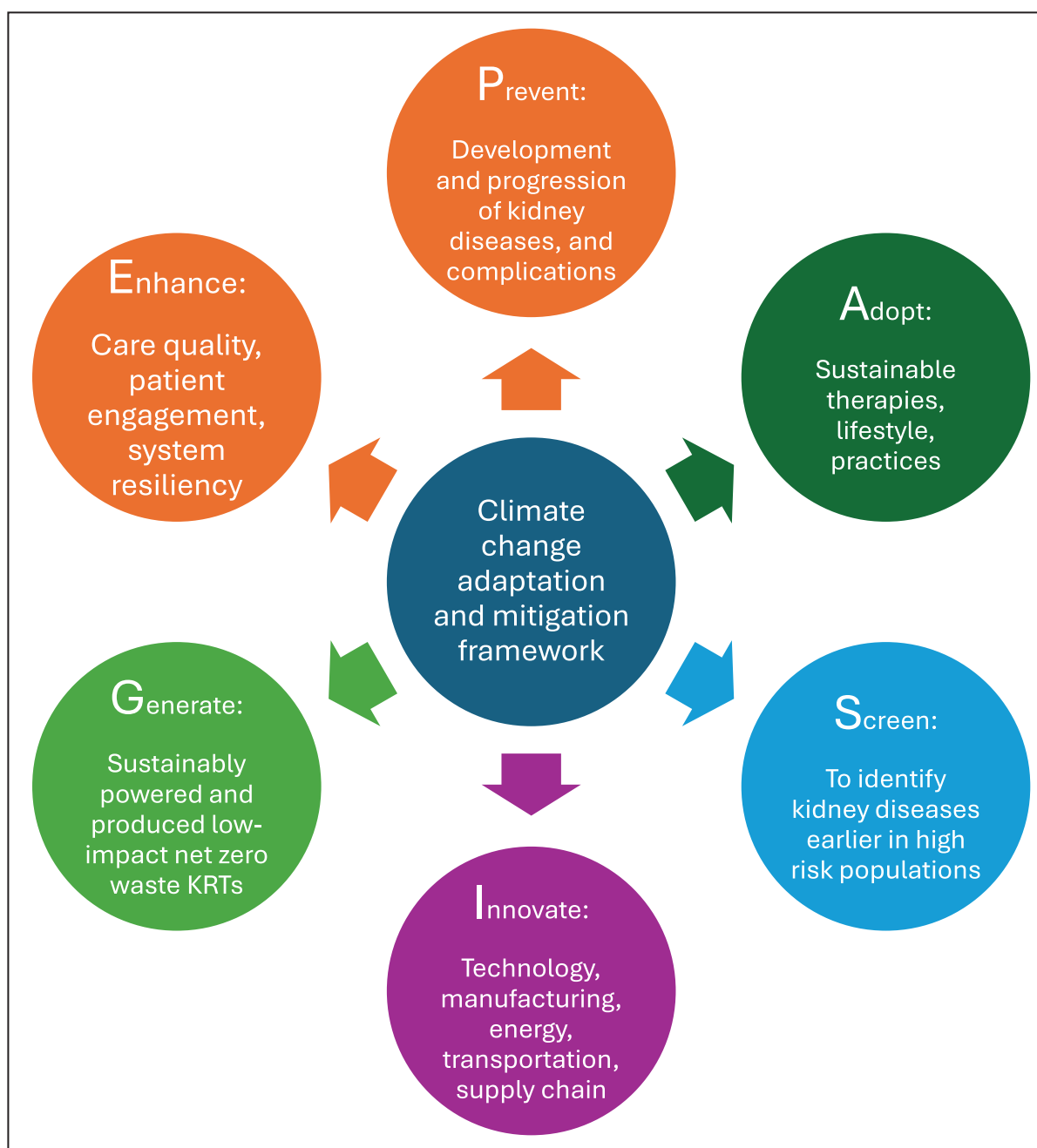


FIGURE 2. 'PASIGE': An adaptation and mitigation framework to integrate climate science into (environmentally sustainable) kidney care planning.

was associated with an increased risk of death-censored graft failure, rejection, and all-cause mortality among kidney transplant recipients [67], and renal function deterioration among patients with primary glomerulonephritis [68]. Overall, climate science-informed targeted strategies can address both the environmental and systemic factors that exacerbate the risk of CKD and its associated comorbidities, ensuring a more proactive approach to kidney care planning.

Adopt

Sustainable lifestyle and practices are generally associated with health benefits and are key approaches toward cardiovascular risk management. Dietary patterns favouring plant-based proteins and lower ultra-processed foods, including the Mediterranean diet and the DASH diet, are associated with slower progression of kidney disease [69]. The most recent KDIGO guidelines recommend a comprehensive and integrated approach to lifestyle modification

[70]. Climate science can offer the approaches and tools to make everyday living more sustainable by identifying high-impact behaviours and choices. In a literature review, 181 lifestyle change options were mapped; however, interconnections between variables that potentially affect the implementation of lifestyle changes were underexplored [71].

Simultaneously, adoption of more sustainable treatment options, that is transplantation, over dialysis should be a core part of ESKC planning. Transplantation is the most sustainable therapy for patients with kidney failure, and also offers better survival and quality of life compared to dialysis [72–75]. Several barriers to transplantation exist globally, and integration of these within a sustainable kidney care framework can significantly enhance kidney care planning as well as patient outcomes. Where appropriate, conservative kidney management should be offered. In select cohorts, it is associated with better quality of life, lower symptom burden, and decreased need for hospitalisation [76].

Screen (for early identification)

There is a lack of empirical evidence to support the universal population-level screening for kidney diseases [70]. A KDIGO Controversies Conference on early detection and intervention in CKD concluded that early identification of CKD in people at risk would likely be beneficial in the community and primary care settings if the programs offer risk stratification and treatment [77]. Nevertheless, experts recommend widescale screening in at-risk populations [70]. Climate science can inform a proactive, data-driven approach using population-based modelling studies, climate data, and public health approaches to better guide the screening and identification of kidney diseases earlier and help identify at-risk populations. For example, in a cost-effectiveness analysis, a decision-analytic Markov model was separately calibrated to simulate CKD progression among ethnic US populations [78[¶]]. Population-wide screening for CKD from ages 55 to 75 years was projected to improve population health, be cost-effective, and reduce disparities. Such studies can also help characterize regional risks. In a simulation study from Australia, the dual impacts of climate change and population ageing were assessed [79]. In the absence of adaptation, they were estimated to increase the burden of kidney disease by 100.2–291.2% when accounting for changes in population size and age structure [79].

Innovate and generate

The healthcare sector is a significant contributor to emissions of greenhouse gases and other pollutants

through energy consumption, transport, and product manufacture, use, and disposal [10,80,81]. In 2018, the healthcare sector's climate footprint was estimated to be equivalent to 4.4% of global net emissions, and if the health sector were a country, it would be the fifth-largest emitter on the planet [80]. Emissions from healthcare facilities and health-care-owned vehicles, as well as indirect emissions from purchased energy sources, account for 29% of the worldwide footprint [80]. The majority (71%) are primarily derived from the healthcare supply chain through the production, transport, and disposal of goods and services, such as pharmaceuticals and other chemicals, food and agricultural products, medical devices, hospital equipment, and instruments [80]. Similar patterns are speculated to occur in nephrology as well. Thus, innovations are needed to improve procurement practices for medications, dialysis equipment, and consumables, with an ultimate goal of circularity and zero waste [41].

A multisectoral approach is needed to enhance energy efficiency in kidney care facilities. Innovations in the use of renewable energy in kidney care facilities can lead to cost savings, reduced carbon footprints, and improved dialysis access in remote areas with unreliable electricity supply, thereby decreasing transportation-related emissions from patient travel [82]. Challenges in waste management have also been described, and innovations in recycling or regenerating dialysis wastewater, provision of high-efficiency incineration when reuse options do not apply and similar strategies and initiatives ought to be pursued using climate science [40[¶]]. Innovations to reducing the use of plastic by switching to biodegradable or compostable material, adopting circular economy models, and establishing plastic-free policies can minimize waste [83]. Overall, the goal is that all innovations generate sustainably powered and produced low-impact net-zero waste kidney replacement therapies, resilient to climate threats [41].

Enhance

Improving and enhancing the care delivered to patients while accounting for emerging climate threats is a core element of the framework. We propose enhancing care by targeting ‘climate resilient and low carbon health systems’, systems that are “capable of anticipating, responding to, coping with, recovering from, and adapting to climate-related shocks and stress, while minimizing greenhouse gas emissions and other negative environmental impacts to deliver quality care and protect the health and well being of present and future generations” [84]. The impact of climate hazards on people living

with kidney diseases is a function of hazard, vulnerability, and exposure [84]. Given the dependence of people with kidney disease on often complex health systems and community structures to deliver uninterrupted therapies, they are uniquely exposed and vulnerable to the disruptive effects of disasters and other climate-related emergencies. A framework in disaster management across the domains of disaster preparedness, response, and recovery in kidney care has been proposed to generate context-specific approaches [85]. Predictive models, early warning systems, and hazard mapping can help conduct risk assessment to climate hazards.

Enhancing ESKC can also include offering the best evidence-based practices, such as initiating risk-modifying therapies, such as mineralocorticoid receptor antagonist, renin-angiotensin system inhibitors, and sodium-glucose cotransporter 2. Including patients in research and practice endeavours, medication stewardship, and development of environmental metrics in kidney quality improvement initiatives for monitoring, evaluation, and accountability are several other approaches to enhance ESKC planning [61]. To advance equity, community engagement is essential, particularly championing Indigenous people as climate scientists and as custodians of unique knowledge and practices to offer effective climate solutions [86].

CONCLUSION

Recognising the need for a systematic approach to advance ESKC planning, we propose a climate change adaptation and mitigation framework called the 'PASIGE' framework to guide climate science integration in kidney care planning. The strength of our framework is that we recommend several evidence-based approaches or best practices in patient care. However, we acknowledge some challenges to implementing the PASIGE framework. A big barrier to implementation is system-level governance challenges due to a lack of interest, capacity, resource constraints, and competing interests. An economic analysis could demonstrate how ESKC is cost-effective while being patient-centric. Also, an important aspect of this framework entails pursuing innovations in manufacturing, technology and procurement. These domains tend to fall outside the direct control of the healthcare sector and depend on the commitment, interest and support of industry partners whose priorities are often shaped by market dynamics and profit-driven incentives. This may limit the implementation of several components of the framework in the absence of engagement from industry partners. Furthermore, there is a need to apply an equity and ethical lens to this framework to

understand its implications on the most vulnerable population and ensure it does not exacerbate health disparities. Lastly, there is a need to refine evaluation metrics by distinguishing environmental and clinical indicators for monitoring, evaluation, and accountability. This requires targeted quality improvement initiatives. Nevertheless, we offer a novel framework for applying climate science in kidney care planning, which has significant implications for the global nephrology community and can drive climate action.

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Conflicts of interest

Dr Sandal has received a one-time speaking honorarium from AstraZeneca. V.J. reports consulting fees/honoraria from Bayer, Astra Zeneca, Boehringer Ingelheim, Baxter, Vera, Visterra, Otsuka, Novartis, Astra Zeneca, Timberlyne, Biogen, Chinook, and Alpine under the policy of all payments going to the George Institute.

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- of outstanding interest

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