The environment and kidney health: challenges and opportunities

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Abstract

The accelerating environmental degradation as a result of modernisation and climate change is an urgent threat to human health. Environment change can impact kidney health in a variety of ways such as water scarcity, global heating and changing biodiversity. Ever increasing industrialization of health care has a large carbon footprint, with dialysis being a major contributor. There have been calls for all stakeholders to adopt a 'one health approach' and develop mitigation and adaptation strategies to combat this challenge. Because of its exquisite sensitivity to various elements of environment change, kidney health can be a risk marker and a therapeutic target for such interventions. In this narrative review, we discuss the various mechanisms through which environmental change is linked to kidney health and the ways that the global kidney health communities can respond to environmental change.

Keywords: environment; climate change; chronic kidney disease; dialysis; carbon footprint

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Resumen

La acelerada degradación ambiental, resultado de la modernización y el cambio climático, es una amenaza urgente para la salud humana. El cambio ambiental puede impactar la salud de los riñones a través de diferentes mecanismos, en donde se incluyen la escasez de agua, el calentamiento global y el cambio en la biodiversidad. La creciente industrialización del cuidado de la salud tiene una cuantiosa huella de carbono, en la que la diálisis es un contribuyente importante. Ha habido llamados a todas las partes interesadas para adoptar un enfoque de "Una Salud" y desarrollar intervenciones de mitigación y adaptación para enfrentar este reto. Debido a su exquisita sensibilidad a varios elementos del cambio ambiental, la salud renal puede ser un marcador de riesgo y, a la vez, un objetivo terapéutico en tales intervenciones. En esta revisión narrativa se discuten los diversos mecanismos a través de los cuales el cambio ambiental está vinculado con la salud renal y con las formas en que las comunidades de salud renal global pueden responder al cambio ambiental.

Palabras clave: medio ambiente; cambio climático; enfermedad renal crónica; diálisis; huella de carbono

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The concept of environment extends to the composite of all physical, chemical, and biological factors external to humans, and related human behaviours.[1] Our environment reflects our way of life and impacts our health. Industrialization, technological advancement, and population growth have contributed to the degradation of this environment. Human activities have been responsible for release of ever-increasing amount of 'greenhouse gases' in the atmosphere. These gases trap infrared radiation (heat energy) and re-radiate it back to the earth. The resultant atmospheric warming has led to changes in the pattern of weather, oceans, land surfaces and ice sheets.[2] Since carbon dioxide makes up most of the greenhouse gases, the term greenhouse gas emission and carbon emission are often used interchangeably. The sober assessment of the planet's future by the UN Intergovernmental Panel for Climate Change (IPCC) makes the need for humans to develop alternatives to the present way of living and energy production so as to reduce harm and protect life and health on our planet more urgent than before.[2,3]

Climate change has been called 'the biggest threat to security that modern humans have ever faced' and a 'crisis multiplier'.[4] According to the Lancet Countdown on health and climate change,[5] climate change is the greatest global health threat facing the world in the 21st century. Despite being an urgent global concern, many health professionals remain unaware of the strong link between environment and health. While the general global economic and technological developments have led to overall improvements in health care delivery, these very health care systems have become important producers of greenhouse gases, especially in high-income countries.[6] Overall, healthcare sectors contribute to 4.4% of global net carbon emissions (expressed as tonnes of carbon dioxide equivalents [CO2]/year), with the USA, China and EU nations contributing to 56% of the total healthcare carbon footprint. All aspects of healthcare contribute –starting from construction and running of hospitals, high-carbon medical products, packaging, waste management, transport, and unnecessary and inefficient medical procedures.[7]

The United Nations Sustainable Development Goal 13 calls for urgent action to mitigate climate change.[8] Mitigation actions are aimed at directly stopping and decreasing the environmental destruction. They need to be combined with adaptation strategies that reduce the negative impacts of environmental change on human health, and/or adjust our current health systems, improve the health system resilience, and anticipate and develop responses to emerging challenges.

In recent years, awareness has grown in the global nephrology community about the adverse effects of environmental change on kidney health. Several national and regional nephrology societies, including the European Renal Association, Australia and New Zealand Society of Nephrology, and the Brazilian and Italian Societies of Nephrology have identified the need of integrating environmental change mitigation efforts into the practice of nephrology and calling for a sustainable "green nephrology" initiative.[9] The goal of this initiative is aimed at promoting sustainability and advancement of planet-friendly practices in caring for kidney disease.

In this narrative review, we discuss how climate and environmental change are impacting kidney health and propose actions to mitigate the impact of kidney health care on the environment to support climate change adaptation within the health systems.

Climate change and kidney health

Climate change affects kidney health and introduces barriers around the ability of patients with kidney disease to access care. Awareness of this link is important as kidney disease usually develops and progresses insidiously, without producing symptoms and signs in early stages. Detection is easy and requires simple investigations, such as testing for increased loss of protein in urine and/or estimating glomerular filtration rate by measuring blood levels of filtration markers like creatinine, but these tests are often not available, especially in primary care settings, in low-income countries.

Heat stress

The most visible impact of environmental change has been the sustained rise in global temperatures, commonly referred to as global warming. The average global temperature on the earth has increased by about 1.2 ºC since 1880.[10] The five hottest years on record on earth have occurred since 2015. The most recent IPCC report suggests that the target of limiting global warming of 1.5 ºC, as laid out in the 2015 Paris accord, is unlikely to be met without drastic mitigation actions.[2]

The increase in number and intensity of heatwaves (sustained temperatures over 40 ºC or temperature increase greater than 5 ºC over the average maximum temperature of the region) and the related mortality and economic loss have been well documented.[11] The impact is disproportionately greater in the developing countries. According to the 2020 report of the Lancet countdown on health and climate change,[5] India and Indonesia are among the worst affected countries, with losses equivalent to 4-6% of their annual gross domestic product due to a heat-related reduction in labour capacity. Cambodia, Thailand, Vietnam, Bangladesh, Pakistan and India experienced the highest work hours lost per person (202, 164, 160, 148, 116 and 111 respectively in 2019). In comparison, the US lost seven work hours per person.

Hot climate has been long known to directly affect kidney health by promoting the development of kidney stone and through heat-stroke-related acute decrements in kidney function (acute kidney injury, AKI), especially when access to water is restricted (figure 1). Dehydration leads to supersaturation of calcium and uric acid in urine and promotes lithogenesis.[12] A number of factors contribute to AKI, such as heat-related rhabdomyolysis, volume depletion and direct thermal injury.[13] Children, elderly and those with chronic diseases such as diabetes mellitus, kidney disease, and heart disease, are at the highest risk of heat related kidney injury.[14] Repeated episodes of heat injury-induced AKI has been shown to be associated with higher risk of chronic kidney disease (CKD).[15]

The recognition of CKD clusters in many regions ("hot spots") in recent years across the world has attracted the attention of nephrologists and public health experts.[16,17] This condition was first described amongst young male agricultural workers in Central America who presented to hospitals with advanced kidney failure. None of these patients had any of the known CKD risk factors. In contrast to the usual presentation of kidney diseases, they did not give history of edema and/or hypertension, and the investigations showed little or no proteinuria. This constellation of clinical and laboratory findings suggests predominant involvement of the tubulointerstitial compartment of the kidneys, confirmed in the reports where kidney histology could be analyzed. Over the last two decades, similar reports appeared from other countries. This condition has now been documented or suspected in Nicaragua, El Salvador, Costa Rica, Guatemala, Mexico, Panama, Sri Lanka, India, Egypt, Tunisia, Cameroon Egypt, South Africa, the Philippines, Taiwan, Indonesia, Thailand, the United States of America (USA), and the United Kingdom (UK).[18]

The etiology of this condition, called CKD of uncertain etiology (CKDu), remains a matter of speculation. Opinion is divided on whether this presentation is due to the same or different causes in different geographies. There is compelling evidence from Central America that repeated episodes of dehydration secondary to exposure to intense heat lead to recurrent episodes of AKI eventually leading to CKD, making heat stress one of the leading contenders as a causal factor. Other contenders include exposure to agrochemicals and pesticides, contamination of drinking water with heavy metals, past infectious insults, congenitally reduced number of nephrons due to maternal malnutrition and genetic factors.[19] Some studies have also shown a positive association between

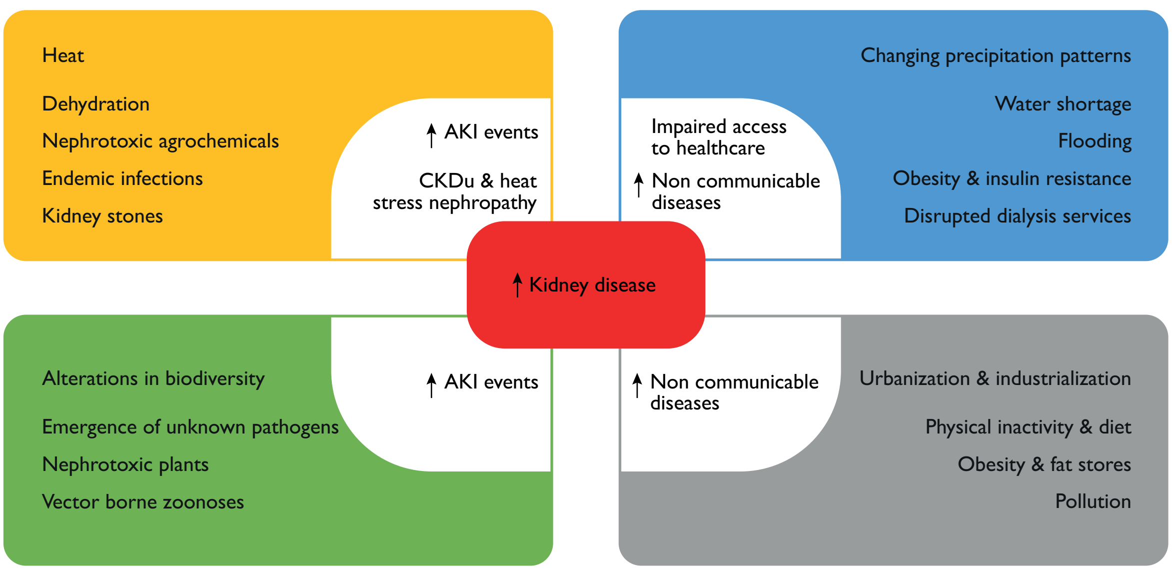

Figure 1. How does climate change affect kidney health and disease?

pesticide exposure and CKDu.[20-22] An environment-wide association study documented the link between environmental chemicals, including heavy metals and agrochemicals, and CKD.[23] Heavy metals such as arsenic, cadmium, lead, and mercury can directly cause kidney injury.[24] The kidneys, by virtue of the concentration and secretion functions, are the main elimination routes for several toxins. These toxins may achieve high concentration in the kidneys in a state of dehydration, increasing the risk of kidney injury.[25] Shortcomings in the design of most studies assessing a link between environmental exposure and CKDu prevent firm conclusions to be drawn. In particular, lack of prospective studies examining lifetime exposure of subjects to specific risk factors and their interaction with coexisting factors makes the assessment of etiology of CKDu difficult.

There have been calls for implementing common-sense public health interventions to reduce the development of kidney injury related to heat and other environmental factors. These include mandating rest and shade breaks, increasing availability of clean drinking water, and regulating pesticide use. Improved working conditions in the form of provision of potable water and scheduled rest periods in mobile shaded areas in El Salvador were shown to reduce symptoms related to heat stress such as exhaustion, nausea, fainting and cramps amongst sugarcane workers.[26] This was accompanied by increased productivity in the study participants.

Extreme weather events

Climate change has also led to changing patterns of humidity, rainfall and wind the world over. A direct consequence is the increased frequency, intensity and duration of extreme weather events resulting in unprecedent floods, drought, storms, and wildfires.[27] These extreme events lay the groundwork for vector-borne infectious disease outbreaks, many of which are associated with kidney injury (discussed later).[28] Heatwaves amplify freshwater shortage as water evaporates from the reservoirs. With rising sea levels, flooding of the coasts with sea water replacing fresh water is anticipated to worsen, placing low-income countries with long coastlines such as Bangladesh, India, China, Vietnam, Thailand, Philippines, and Indonesia at particular risk. There are emerging data from Bangladesh that increased drinking water salinity is associated with increased blood pressure and proteinuria, both of whom are linked with progressive kidney disease.[29] The health of the kidney could be impacted directly by both dehydration and the intake of unsafe water.

Food security

Climate change has an impact on production, access, and utilization of food. On the production side, it can impact crops, livestock, forestry, fisheries, and aquaculture, whereas access and utilization are hindered by displacement, trade disruption, and reduced incomes. Suboptimal nutrition impacts kidney health in several ways –maternal malnutrition leads to low-birth weight babies who are at risk of kidney disease later in life, whereas distortions in the quantity and quality of appropriate types of food, for example fruits and vegetables, increases the risk of development and/or progression of kidney diseases.[30]

Water scarcity

Changes in regular weather and precipitation pattern impacts availability and quality of fresh water. Water shortages are increasingly globally, as indicated in reports from Cape Town (South Africa), Chennai (India) and the regional Australian water crises. According to the United Nations World Water Development Report 2018,[31] 47% of the global population lives in areas with water scarcity for at least one month each year. By 2025, two-thirds of the world population is projected to be facing water stress, and around 1.8 bn people will be living in countries with absolute water scarcity.[32]

In addition to contributing to the risk of AKI and stones, water shortage and dehydration are linked to obesity and insulin resistance,[33] which predispose to CKD. Availability of reliable water supply is critical to kidney care delivery. Requirement of large amounts of high-quality water for hemodialysis (HD) (~400-500 litres per person per session) makes the dialysis population particularly vulnerable to water shortage. There are reports of dialysis centers in areas with water shortage obtaining water supply through tankers. Getting water from unconventional sources can be risky, as was shown in an accident reported in Brazil, when reservoir water was used for dialysis and led to microcystin toxicity manifesting as liver failure, visual disturbances, nausea, vomiting, and muscle weakness.[34]

Climate change related migration

Extreme weather events displace populations and interrupt dialysis services. Care of individuals with advanced CKD, in particular those on dialysis is particularly vulnerable because they are forced to migrate or hospital facilities, including dialysis units, are forced to close.[35] Patient vulnerability is more common in developing countries as they are not equipped to mount an effective response to crises.[36] These events are wake-up calls to implement ways to make dialysis services more sustainable and environmentally friendly.

Air pollution and kidney health

The association between environmental pollution and kidney health was shown by demonstration of ecological links between the concentration of ambient particulate matter and kidney disease from the USA and China.[37] Unfortunately, data are not available for countries such as India, Bangladesh, and Nigeria that have seen significant increases in air pollution in the recent decades.

Several societies in developing countries depend on cooking stoves that use biomass fuel (organic matter derived mainly from animal wastes that have low energy densities than fossil fuels) that contribute to indoor air pollution. Harmful gas emissions from burning of plastic waste, including packaging material used for healthcare devices, which has been increased throughout the Covid-19 pandemic. This, and crop residue burning, an agricultural practice of intentionally setting fire to the straw stubble that remains after grains have been harvested, are important sources of toxic gas emissions. Both ambient and household air pollution have been linked to chronic diseases and death in the emerging economies.[38,39]

More studies are needed to understand whether these changes impact all types of kidney disease or increase vulnerability to specific conditions. For example, a study from China documented a strong temporal link between the long-term exposure to air pollution, as measured by increased ambient $PM_{2.5}$ concentration (a mixture of solid and liquid particles with a diameter of <2.5 micron), and the incidence of membranous nephropathy, an autoimmune disease characterised by increased protein excretion in urine and increased long-term risk of kidney failure.[40]

Urbanization and industrialization

Increasing urbanization and industrialization have changed the traditional hunter-gatherer lifestyle to the modern sedentary habits.[41] They have resulted in shrinkage of space available for outdoor physical activities, especially in large cities growing rapidly throughout the developing world. Increasing reliance on rapid transport, proliferation of sedentary jobs (exacerbated during the Covid-19 pandemic), and increasing consumption of calorie-dense foods have culminated in the obesity epidemic as well as increased rates of diabetes mellitus with adverse impacts on kidney health. Regular physical activity is associated with slowing the progression of CKD.[42] Physical activity, and hence health, of human beings is determined largely by the built environment.[43] Therefore, any mitigation response to climate change will need to include increased space for walking, bicycles, green spaces, and parks.

Ecological disturbance

Human activities have adversely affected natural ecosystems and biodiversity (variability among all living things on earth). In addition to humans, changing climate and extreme weather events force migration of animals and birds, increasing the interaction between humans and unfamiliar pathogens, vectors and hosts. The resultant loss of biodiversity increases the range of hosts for these pathogens resulting in more frequent infectious disease outbreaks over wider geographic areas including the emergence of still unknow pathogens for humans, such as the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the causative agent of the current pandemic of Covid-19.[44,45]

Effect of climate on vectors and pathogens

Warm climate promotes migration of mosquitoes and other warm-weather vectors to higher altitudes and new regions farther from the equator where they could not survive earlier, and increases the range of reservoir hosts and biting rates, thus increasing the rates of transmission of parasitic diseases.[46]

Risk modelling has shown that the climate of central North-western Europe is now warmer and wetter, making it favourable for *Aedes* mosquitoes, a vector for several viral diseases that cause kidney injury. Similarly, new areas of South-eastern Africa and China have become vulnerable to the spread of schistosomiasis, a disease caused by parasitic flatworms called schistosomes that infects the urinary tract or the intestines and can causes urinary tract obstruction and kidney failure.[47,48]

Biodiversity is also affected by unsustainable agricultural activities that change land use.[49] The increasing need for agricultural land is met through deforesting and displacement of forests-dwelling species. Moreover, pesticides, fertilizers, and practices like tillage are harmful for wild plant and insects in the soil. Therefore, biodiversity loss also affects food security as plants and animals become more vulnerable to pests and diseases.[50]

The immediate impact of biodiversity loss on kidney health is likely to manifest as kidney injury following emerging the spread of vector-borne zoonoses to new areas as well as increase in the intensity of endemic infections.[51] Zoonotic outbreaks such as West Nile virus, SARS, MERS and now Covid-19 have been directly linked to biodiversity loss.[52] AKI has been an important and consequential complication of Covid-19 infection. In fact, urinary abnormalities have been suggested as an early feature for predicting development of future complications and need for escalation of therapy in Covid-19.[53]

The increasing recognition of the link between human health and animals, plants and their shared ecosystems, has introduced the need to adopt the 'One Health' approach.[54] This is defined by the World Health Organization (WHO) as an approach to designing and implementing programmes, policies, legislation and research in which multiple sectors communicate and work together to achieve better public health outcomes. Figure 2 summarises the key consequences of climate and environmental changes on kidney health and disease.

The adverse impact of kidney care on environment

Amongst various medical procedures, dialysis has a particularly large carbon footprint.[55] Dialysis service was shown to contribute to 62.5% of all carbon gas emissions in a renal service in the UK.[56] Data from developed countries like Australia, the UK, and France have shown carbon emissions in HD units to be ~3.8-10.2-tonnes CO_2 equivalents/year. A large part of this carbon footprint is attributed to energy consumption including electricity, water, and gas during HD.[57] Per capita, home-based HD has a larger carbon footprint than in-center HD, largely because of greater treatment frequency (5-6 times versus 2-3 times a week, ~20 kilowatt/session).[58,59] Travel adds to the carbon cost of in-center HD.

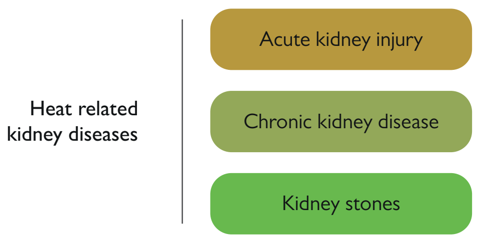

Figure 2. Examples of heat-related kidney diseases

The carbon footprint of home-based peritoneal dialysis (PD) is attributed to packaging and transportation of materials, electricity (for automated PD), and waste disposal.[60] Both HD and PD lead to generation of plastic wastes - each session of HD typically generates 1-5 kg of potentially hazardous waste whereas PD contributes to about 2.5 kg waste per day. This waste is non-recyclable and pollutes the environment, and its disposal carries a carbon cost.[61]

According to a 2015 systematic review, 93% of world's dialysis is in high and upper-middle income countries.[62] This contrasts with the rapidly increasing burden of people requiring kidney replacement therapy in low and lower-middle income countries (LMIC) which currently is largely unmet.[63,64] LMIC estimates of the need and prevalence of kidney replacement therapy are also limited by absence of registries. The anticipated rapid growth and improved documentation provides an opportunity to policymakers and administrators in countries looking to set up/expand dialysis services to make suitable adaptation and include environment-friendly practices.

Interaction between environment change and socioeconomic determinants of health

A 2016 WHO report attributed 23% of global deaths to modifiable environmental factors, with the burden being highest in low-income countries. Compared to developing countries, the developed nations emit higher per capita emissions. This means that populations that have contributed the least to the problem are the worst affected.[1] While the entire populations in socioeconomically disadvantaged communities are affected by adverse environmental change, women, children, and elderly represent the most vulnerable groups.[65] Moreover, many groups are unable to protect themselves against the threat of environment change. These include those dependent on manual work in harsh outdoor conditions to make a living, those without access to regular clean drinking water, women who cook on stoves that use biomass fuel, and people without access to healthy food or appropriate spaces for physical activity. All of these factors predispose to or worsen kidney disease. People's ability to access kidney care is also affected by environment change. In particular, the Indigenous people and tribes across the world are intimately connected with their land and communities for economic and sociocultural livelihoods. Climate change has forced many such Indigenous populations to relocate to cities, which reduces their access to important social support.[66] In addition, Indigenous people usually have usually lesser access to health services than non-Indigenous people, and experience historical discrimination, which may result in getting a dialysis more often than to a full kidney transplant.[67] These factors contribute to reduced survival of Indigenous people and tribes.[68]

How should the kidney health community respond to environment and climate change?

The mitigation and adaptation actions needed to minimise the impact of climate change on kidney health cannot be discussed solely in terms of impact on kidney health. A whole of society and whole of government response that holistically addresses this agenda in a holistic manner is required for effective change.

Global collaborative research is needed to develop sensitive markers to study the impact of environmental factors on human health that will allow targeted interventions. Kidney health professionals can play a vital role in such a health system response. It has been suggested that the sensitivity to various elements of the environment makes the kidney as the sentinel organ to measure the impact of climate change on human health before manifestations appear in other organs through simple markers –*e.g*. proteinuria and eGFR. Moreover, many climate mitigation actions can have kidney health co-benefits. For example, a switch from meat consumption to more plant-based diets and shift from motorised to non-motorised modes of transport reduce carbon emissions and at the same time have a salutary effect on kidney health.

Research is also needed to understand better the interactions between environmental and non-environmental factors and pre-existing conditions. We need to expand our current risk prediction tools to include the impact of these emerging risk factors. We also need to improve our understanding of the impact of these changes on the health-seeking behaviour of the affected populations, so that sustainable and holistic solutions can be developed and implemented in a manner consistent with the values and preferences of local societies.

The kidney health community has a responsibility to contribute to the mitigation efforts, given the large carbon footprint of kidney care.[56-61] Adapting dialysis delivery is a suggested start, with focus on developing eco-friendly dialysis units and investment on innovations, such as the Affordable Dialysis System being developed through an initiative of the International Society of Nephrology and the George Institute for Global Health,[69] and the programs under the KidneyX initiative of the American Society of Nephrology.[70] Carbon trade-offs should also be included in the study of any new dialysis interventions. We need to develop ecological performance indicators of dialysis such as energy consumption, carbon footprint, amount and type of waste generation, and water consumption.[59]

Additional research is needed to evaluate the environmental impact of kidney care, including data to improve understanding of links between environmental factors and specific kidney diseases, studies of pathophysiological mechanisms, and developing appropriate responses particularly in settings with fragile health systems. Special attention is needed on the vulnerabilities of populations with limitations in achieving their full biological development due to environmental factors, starting from in utero and developing disease at younger ages.[71] Education and guidance are needed to sensitize the kidney care community about the impact of climate change and sustainable kidney care. This requires multidisciplinary research and collaboration with implementation experts.

While there is an extensive list of strategies to tackle the environmental impact of dialysis,[56] some steps can be adopted immediately (table I,[56] figure 3). With the cutback of transportation and physical outpatient visits after the beginning of the Covid-19 pandemic, telemedicine and the transition towards digital health have seen a boom.[72] A recent study showed major health gains in patients on PD who used telemedicine compared

Table I
Strategies to tackle the environmental impact of dialysis

- Reuse of reverse osmosis reject water for laundry, toilet and gardens in hospital buildings
- Use of centralized water preparation system that combines water treatment and dialysis preparation
- Improving water purification systems to reduce the amount of reject water
- Using alternative energy sources for electricity such as solar powered dialysis machines
- Using energy-efficient devices such as light-emitting diode bulbs and motion detector lighting in dialysis units
- Investing in environmentally sustainable dialysis equipment and procedures by including life-cycle analysis information while choosing devices
- Improved waste segregation and disposal through education and regulations
- Encouraging active transport or public transport to patients and staff by means of educational platforms
- Making ecologically sustainable hospital buildings
- Encouraging electronic record keeping, while keeping track of energy consumption in digitalization
- Inclusion of environmental variables as indicators of performance of dialysis service providers
- Including considerations of carbon cost while developing personal treatment plans
- Examine the entire dialysis experience – and find possible steps to reduce carbon emissions.

Adapted from reference 56

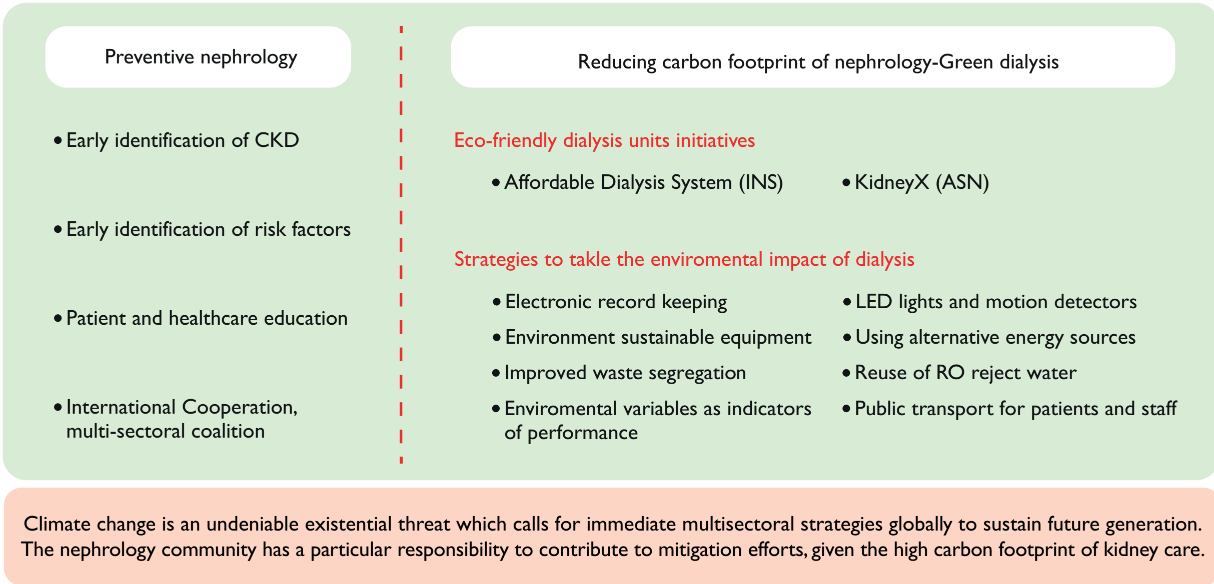

FIGURE 3. HOW CAN NEPHROLOGY HEALTH-CARE SYSTEMS RESPOND TO ENVIRONMENTAL AND CLIMATE CHANGES?

to those who did not.[73] Many countries, including the US, have developed guidance and toolkit for providers to help establish and operate a telehealth program to manage patients on dialysis who are at risk of morbidity and mortality if infected by Covid-19.[74] However, telemedicine is not carbon neutral, and its impact on environment needs to be studied further.

Finally, the day-to-day patient care and nephrology education, including conferences and meetings, have a significant carbon footprint, due to extensive (often intercontinental) travel and other meeting-related logistics. The travel restrictions forced upon us by the SARS-CoV-2 infection have shown us that a significant proportion of these activities can be conducted remotely and be accessible while reducing their carbon footprint.

In conclusion, if not addressed, the burden of environmental change on kidney health is likely to be disproportionately large on those living in the developing countries with feeble healthcare systems.[75] Finding mitigation strategies will lead to health and financial benefits. The agenda for mitigating the impact of environmental change on health, and specifically kidney health, should be structured around building awareness, education, international cooperation, multi-sectoral coalition, and policymaking guidance. Countries should focus on measures to reduce carbon emission and preserve natural resources.[76]

Clearly, "Think globally, act locally" is the mantra for every dimension of combating environmental impact of healthcare. The onus lies on each and every individual to reduce the impact of their activities on the environment.

Declaration of conflict of interests. The authors declare that they have no conflict of interests.

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