



**PROVISION OF CLEAN WATER THROUGH REVERSE OSMOSIS: COST-EFFECTIVE INTERIM SOLUTION TO OVERCOME WATER-POLLUTION-RELATED DISEASES**

**Sunil J. Wimalawansa\***

Medicine, Endocrinology and Nutrition, Cardio Metabolic Institute, N.J., U.S.A.

\*Corresponding Author: Prof. Sunil J. Wimalawansa, MD, PhD, MBA, DSc

Medicine, Endocrinology and Nutrition, Cardio Metabolic Institute, N.J., U.S.A.

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**ABSTRACT**

Human diseases due to water contamination occur mostly through agrochemicals, manufacturing processes, industry pollutants, geogenic natural elements, livestock and sewerage, anthropogenic contamination, and natural disasters. This review focuses on waterborne diseases, using chronic kidney disease of multifactorial origin (CKDmfo) as an example. The latter is estimated to kill approximately 40,000 people each year worldwide; mostly in tropical countries. Irrespective of whether a disease is acute or chronic, when the disease originates from contaminated water, provision of clean water becomes a key requirement. The method to be used to generate purified water depends on the assumed causative factor(s) and availability of local water sources. Most contamination occur through microbes, chemicals, and toxins. The optimum mode of purification depends on the level of contamination, molecular size of the expected agent, type of toxin, geographical area, size of the population affected, source of available water, and severity of the problem. A membrane-based water purification technology, such as the reverse osmosis (RO) method, can be made available swiftly and cost-effectively to provide water, on a small or large scale, including during times of natural disasters and after other emergency situations. Especially when the causative factors in water are unknown, a membrane-based water purification technology is the best interim solution for providing clean water. If the molecular masses of the offending agents are larger than 100 Daltons, they can be effectively removed from water with the use of RO membranes but not through nano-filtration systems. RO is a cost-effective interim solution that can be implemented quickly until a centrally purified, pipe-borne water supply is provided or restored in affected communities. The RO procedures remove complex and biological toxins, heavy metals, agrochemicals, bacteria, fungi/spores, colour and odour, and suspended particles in a single pass through RO membranes, making water safe for human consumption. Toxic chemicals are not added to the water during the RO procedure. Thus, the quality of water when released back to streams is not different from the inlet water, so the procedure is environmentally friendly and safe. Installation of an RO unit is straightforward. When surface water or groundwater is used (in contrast to factory discharges) the RO rejects do not need any special treatment. The RO process should be supplemented by rainwater and other freshwater collection methods. RO is the most cost-effective way to produce an interim supply of safe, clean water devoid of toxins, microbes, heavy metals, colour and odour and unpleasant taste, and disease-causative agents.

**KEYWORDS:** CKDu; CKDmfo; Environment; Health; Membrane technology; Non-communicable diseases; Pollution; Premature deaths.

**INTRODUCTION**

In addition to waterborne diarrhoeal diseases, the incidences of several non-communicable diseases are rising worldwide, especially in developing countries.<sup>[1]</sup> The relationship between tap water and health has been highlighted in many public health programs.<sup>[2][13]</sup> The incidence of toxin-induced diseases has escalated during the past four decades in suburbs and in agricultural and manufacturing regions. Whether these illnesses are acute or chronic, the provision of clean water to the affected communities is one of the prime actions needed to resolve the problem.

Because of its unique molecular nature, water is considered to be a universal solvent.<sup>[3,4]</sup> Whether water is distilled, solar condensed, deionised, purified by reverse osmosis (RO), or rainwater collection (RWC), all sources of water can dissolve virtually anything, in pico-, nano-, or micro-molar quantities, or even higher. Because no sensible person drinks distilled or deionised water on a regular basis, these two aspects are not discussed here.

The ability to dissolve substances in water is also influenced by the temperature, pH, and other constituents in water. Because of concerns and a lack of trust regarding the quality of pipe-borne water, approximately

20% of the world's population consumes bottled water, which is the costliest way to obtain clean water and some supplies cannot be relied upon. Annual revenue from the bottled water industry currently exceeds \$240 billion.<sup>[4,5]</sup> Most bottled water is derived from streams, natural springs, or after purification through RO technology.

Despite this, thousands of villages and communities, an estimated 1.8 billion people around the world, do not have access to a safe, clean water supply, and the majority of them cannot afford to purchase bottled water.<sup>[6,7]</sup> Consumption of water polluted by microbial agents, chemicals, or toxins can cause serious illnesses. Thus far, the Millennium Development Goals set by the United Nations (UN) have unfortunately not been accomplished with regard to access to clean water and safe sanitary facilities.<sup>[7-9]</sup>

In addition, worldwide several million people die each year because of a lack of clean water.<sup>[7,10,11]</sup> This article discusses the rational basis for using the RO method for water purification in situations in which clean water is essential, whether the need is for a few days or a few years, for curbing escalating water-related diseases and preventing disease spread. It also compares the cost of generating clean water from RO with the standard RWC systems in the community.

#### **Purification needs vary, depending on the situation**

Outbreaks of waterborne diseases have demonstrated the vulnerability of the water supplies and health of the general public to biological and chemical contamination of drinking water.<sup>[12]</sup> If the water requires treating for safety reasons, the bottlenecks to success are the technology used; the availability of treatment facilities and trained operating personnel; and costs.<sup>[1]</sup> The solution needs to be sustainable within the local economic context. Being dependent on outside resources and charities for a continuous clean water supply is not sustainable.

Traditionally, the long-term solution is to set up central water treatment plants together with piped distribution networks that carry water to individual houses. Such efforts are hampered by high capital costs, operation and maintenance inadequacies, lack of priority and political will, inefficiencies in management, and finances.<sup>[1]</sup>

In addition, the lack of will and unpreparedness of local governments to deal with chemical and microbial contaminants; geogenic contaminants, such as fluoride, cadmium, arsenic; and anthropogenic contaminants, such as fertilizer, pesticides, petroleum, heavy metals, and industrial and factory discharges make the situation worse. This lack of governmental readiness for potential demands during acute or chronic disasters invariably leads to doing nothing to alleviate the problem or opting to use expensive technologies.<sup>[13]</sup>

#### **Water supplies through public networks**

In developing countries and in emerging economies, a significant proportion of the population does not have access to a centrally purified, pipe-borne drinking water supply. Because these communities are economically poor, they cannot afford to purchase bottled water.<sup>[14]</sup>

During the past two decades, there has been relentless marketing worldwide and a consequent continual increase in bottled water consumption. This is in part because people do not trust the quality of well water or even pipe-borne water.<sup>[15]</sup> These fears are strengthened by deceptive advertising by bottled water suppliers; bottled water sales are a lucrative market with high profit margins.

Nevertheless, when communities are affected with water-related health conditions, it becomes necessary for individuals to purchase potable drinking water or for governments or charitable organizations to provide water treatment facilities or potable water supplies for involved communities.

A pattern of consumption differences exists related to water supplies, based on local regulations, trust, perceived controls, cultural background, location, and past experience.<sup>[2]</sup> Consumers' perception of the quality of bottled water compared with that of drinking water supplied through the public water supply networks is a matter of ongoing controversy.<sup>[16,17]</sup>

#### **Community faith in public water supplies**

In many communities, the public does not trust the government or local administration. Thus, the perception is that the quality of water provided through the public systems is inferior, and bottled water is perceived to be of better quality.<sup>[17]</sup> Despite the marked differences in cost, these consumer perceptions affect drinking water preferences and consumption patterns.

In a study assessing the association between diarrhoeal risks and community-scale water treatment and refill kiosks, authors concluded that there were no significant differences in diarrhoeal risks for those who consumed water from kiosks or bottles compared with those who consumed water from wells.<sup>[14]</sup> Most participants perceived that bottled water conferred general health benefits but were unsure as to the nature of such benefits.<sup>[15]</sup>

Despite the lack of scientific evidence for such perceptions, many believe that added minerals in some bottled water confer a health benefit.<sup>[4,15]</sup> Added minerals can improve the taste of water but do not add nutritional value.<sup>[13]</sup> Hardly anyone understands that exposure of plastic bottles to direct sunlight (i.e., UV rays), a common practice among farmers, can lead to the leaching of harmful chemicals into water. Nevertheless, most users believe that plastic bottles have a detrimental effect on the environment.<sup>[15]</sup>

### **The importance of drinking safe, clean water**

Clean water for drinking and cooking is essential for maintaining health and for human survival. Thus, each country must have or at least have a plan for implementing a sustainable national water policy.<sup>[12,18,19]</sup> In addition, policies and regulations are required to establish safe infrastructure for sustainable drinking water supplies and safe disposal of sewerage and proper drainage, not only in cities but also in rural regions.<sup>[18]</sup> In addition, planners need to pay attention to how the public and private sectors value and use freshwater resources, watersheds, and farmlands.<sup>[20-25]</sup>

Policy options for securing sustainable water supplies for a region or province depend on the cost-effectiveness, probability of success in achieving water-saving goals, political willpower, and acceptance by villagers of the policy.<sup>[25]</sup> The strategy of constructing a dam to store and control floodwater is a way to save water, at least in the short term, and in general, farmers are in favour of it. However, this option may not be cost-effective and can be environmentally harmful.

National water resources should include not only potable drinking water but also water for other essential services, such as agriculture, power generation, transportation, fire suppression, and so forth.<sup>[12,19]</sup> Thus, the disruption of these systems is likely to impair public health systems and increase safety risks and vulnerability, opportunity costs, and economic losses. Therefore, securing freshwater systems is critical for national food and water security and the entire economy.

Encouraging farmers to adopt water-saving practices has many long-term benefits and is cost effective; however, it may not be sufficient for achieving the goal of saving water.<sup>[25]</sup> Converting lands traditionally devoted to paddy crops to dry land crops has high public resistance and, in many cases, is impractical; thus, such a plan is unfeasible for large-scale saving of water.<sup>[25]</sup>

### **DESCRIPTIONS AND RESULTS**

#### **Having safe water and sanitation increases life expectancy**

No intervention has greater overall impact on human health, happiness and longevity, national development, and public health than the provision of safe drinking water and the proper disposal of human waste.<sup>[8,11,26-29]</sup>

Comparative risk assessments are needed to assess the effect on morbidity and mortality of using unsafe water and sanitation in each community.<sup>[30,34]</sup> In fact, the key reason for the increased life expectancy of humans (i.e., it doubled during the last century in most countries) was because of the provision of sanitary facilities and safe drinking water.<sup>[6-8,11,30-33]</sup> Science and modern healthcare also contributed to increased life expectancy but in smaller proportions.

Although demographic variables are not necessarily good predictors of life expectancy, improvements in the environment and proactive disease preventive efforts collectively are predictors of enhancing life expectancy.<sup>[31,35]</sup> Thus, together with proactive planning, enforcing environmental laws, and assuring sustainability, continuous improvements in expanding water and sanitation facilities are essential.

In parallel, disease prevention efforts such as health education, mass immunization, and control of harmful animals and insects such as mosquitos are essential to reducing communicable and non-communicable diseases and morbidities, and improving life expectancy.<sup>[7,8,11]</sup> Nevertheless, there are significant disparities in health outcomes caused by social status, economic and environmental risks, inaction, and taking sub-optimal or wrong actions because of ignorance, bias, or political wrangling.

Advances in nutrition, sanitation, availability of clean water, medical and non-medical technology, and medications have also had an impact on increasing life expectancy<sup>[30]</sup> but not necessarily lives without disabilities. Health is a choice that an individual makes; it should be a priority. Proactive public health efforts like the provision of medical interventions, immunizations, and the prevention of outbreaks are keys to economic development, maintenance of good health, the growth of gross domestic products, and poverty reduction in a country.

Preventative healthcare is as important as acute medicine but is neglected in most countries. It includes the control of diseases, such as HIV/AIDS, other sexually transmitted disease, vector-borne diseases, diabetes, osteoporosis, cardiovascular disease; and the prevention of trauma (accidents and injuries), mental disorders, and cancer.

Currently, approximately 40% of people in developing countries, of which more than 80% live in rural communities, do not have access to safe drinking water and safe sanitary facilities.<sup>[6-8,11]</sup> Consequently, at any given time a third of these vulnerable populations have one or more health-related problems, including parasitic diseases that are also related to shortages of clean water and lack of safe sanitation.

#### **The need to improve access to clean water**

*One example of the need to improve access to clean water is presented here.* The North Central Province (NCP) in Sri Lanka is a predominantly agricultural region with a population of over 2.0 million. During the past three decades, people in this province began to experience a deadly disease: chronic kidney disease (CKD) of multi-factorial origin (CKDmfo),<sup>[36-39]</sup> also known as CKD of uncertain aetiology (CKDu) [40-42]. In recent years, the disease has spread outside the NCP region into distant areas; more than 3 million people are

currently at risk for contracting this disease, and the death rate continues to increase.<sup>[36,39]</sup>

Approximately, 85% of the population in the NCP region relies for water on shallow wells and tube wells for their daily domestic water requirement.<sup>[36,40]</sup> More than 90% of those who have CKDmfo consumed water from these sources. The remainder of the population uses water from reservoirs, canals, natural springs, and streams. Those who consume water from these sources have a significantly lower prevalence of this disease. Currently, safe water is available to only approximately 15% of the population at risk in the NCP.<sup>[4]</sup>

#### **CKDmfo (CKDu) is an environmentally induced, occupational disease**

All available data suggest that the disease is contracted by drinking contaminated water over a prolonged period. Consequently, the provision of safe, clean water to all CKDmfo-affected regions should be a national priority.<sup>[36,43]</sup> The disease is not unique to Sri Lanka; a similar disease is present in several other equatorial (tropical) regions and countries, such as Central America, the Balkan region, Peru, China, India, and Bangladesh.<sup>[36,44]</sup>

In Sri Lanka, CKDmfo clinically manifested in early 1990s, whereas a similar disease was documented in other equatorial countries in the mid-1970s. Because of the prolonged exposure needed and the lag time before clinical presentation and diagnosis, causative factor(s) must have been present in CKDmfo-affected regions for 15 to 20 years before the manifestation of the disease.

#### **PHILOSOPHICAL ARGUMENTS**

##### **A global perspective of CKDu/CKDmfo**

There are many similarities related to the disease in CKDu-affected countries. These countries are located within 1,000 kilometres of the equator, climatic conditions are hot and humid, and populations are economically poor. The main economic base of all affected regions in these countries is agriculture. However, non-agricultural workers are also affected.

Other common and similar characteristics include geographical distribution of disease clusters, landscape and topographies, difficulty in identifying a causative factor (perhaps, due to the multi-factorial nature of the disease),<sup>[36,43]</sup> and a high incidence among those who consume stagnant water (e.g., dug wells).<sup>[36,39,45]</sup> These variables collectively suggest a geogenic and "geo-water environment" is triggering this CKDmfo epidemic in Sri Lanka.<sup>[37,46,48]</sup>

In the Balkans and China, the disease has been attributed to excessive consumption of aristocholic acid-containing food/medicine,<sup>[49-51]</sup> and in Bangladesh, the high content of naturally occurring arsenic in drinking water has been reported as a causative factor.<sup>[52,53]</sup> With reference to the cause, no conclusions have been made in other countries

affected with CKDu/CKDmfo, including in Sri Lanka.<sup>[36,43]</sup>

All CKDmfo-affected nations have predominant agriculture-based economy, and the affected rural populations are poor, and many suffer from malnutrition. All nations touched by these diseases are affected with global warming—El Niño effects with prolonged dry spells with flooding in between. Because of the climatic effects on outdoor workers, frequent dehydration has been suggested as a cause in the development of CKDmfo,<sup>[54]</sup> but no convincing data are available to support this theory.

Irrespective of such speculation, the alleviation of chronic dehydration, particularly in outdoor workers, is beneficial to the preservation of renal function and health in such workers. Increasing their daily water intake may minimise progressive renal damage in those who are already affected and prevent disease in those with normal renal function.<sup>[36,55]</sup> Thus, the provision of safe, clean water to inhabitants in CKDmfo-affected areas is a priority that unfortunately has been neglected for decades.

##### **Who is responsible for providing clean water?**

Having access to clean water is a civil right; the government has the fiduciary and moral responsibility to provide clean water to all citizens irrespective of their ethnicity, social status, skin colour, or geographic location.<sup>[56,57]</sup>

The current mandates in most developing countries and in emerging economies, including in Sri Lanka, are for their national water supply and drainage boards (NWS&DBs) to provide a centrally purified, pipe-borne, safe water supply to all inhabitants as soon as possible. This applies not only to disease-affected regions, such as those affected by CKDmfo in Sri Lanka and other tropical countries, but also to all regions.

Therefore, the NWS&DB must focus on its co-competencies: installation of industrial-scale, reliable water purification facilities; development of a network of underground pipes, construction of overhead tanks, a household distribution network, and other integral amenities to accomplish this task in a sustainable manner.

Instead, the government has instructed the NSW&DB to divert its focus and engage in installing RO units in the NCP. This will only further delay the progress of providing a pipe-borne, clean water supply to the region. Despite the serious issues related to this water-related disease in Sri Lanka, neither the government nor the NWS&DB have a nationwide sustainability vision or a master water plan for the provision of fresh water (including potable water) to the NCP or to the entire country.

In Sri Lanka, the NWS&DB has projected that it will take a minimum of 30 years to provide a pipe-borne water supply to CKDmfo-affected regions. In the absence of providing such vulnerable regions with potable water, during this lag period, it is estimated that an additional 280,000 people, predominantly farmers, will perish from this waterborne disease. Therefore, it is mandatory to provide an interim supply of clean water for everyone in the region as soon as possible; not doing so is unethical. However, the water supply needs to be purified to remove chemicals and toxins; accessible and affordable for villagers; and sustainable.

Because of the high governmental overhead (estimated to be approximately three times the real cost), the installation of RO units by the NWS&DB and other government entities is a waste of large sums of taxpayer funds. For example, for each RO unit installed by the NWS&DB, an established local charitable foundation can install three RO units, similar or better in quality and capacity. This is exemplified by the recent request by the NWS&DB for the government to fund an additional \$800 million to provide clean water to the CKDmfo-affected population in the NCP, but the plan covers only a third of the population in the region.

If the government is willing to spend 5% of this anticipated cost, it can provide an interim clean water supply to each inhabitant in the entire region for the next 25 years (at least until the pipe-borne water supply is installed). In fact, that would pave the path to eradicating this deadly disease from the country. The author estimates that doing so would save more than \$13 million (~2 billion rupees) each year. What prevents achieving this savings is a lack of focus, understanding, political willpower, and common sense; and continued conflicts of interest and political interference.

#### **The fiduciary responsibility of the Water Board**

If the NWS&DB can provide clean and safe water to the NCP promptly, that would be a great relief to the residents and would lead to a reduction of persons acquiring this fatal disease. However, if the NWS&DB provides pipe-borne water to the NCP region, it must guarantee that the delivered water is safe for human consumption without any additional treatment in individual homes. Most people in the region cannot afford to treat water. If the NWS&DB can provide safe water, that would negate the need for RO and the use of the two most expensive means of obtaining clean water: bottled water or boiling water before consumption. This would save a considerable amount of hardship to citizens.

Because CKDmfo is directly linked to the consumption of polluted water, the NWS&DB must certify that the water provided by the agency will not cause CKDmfo (i.e., contains near zero nephrotoxins). Without such a guarantee (which comes with accountability), such expensive efforts to provide a pipe-borne water supply

using traditional water purification methods by the NWS&DB would be not only an immense waste of funds but also unethical; farmers will continue to die prematurely.

Water in the NCP region is polluted with multiple smaller molecular-weight, nephrotoxic agents and ions, including fluoride.<sup>[58-60]</sup> These chemicals, including unidentified toxins and agents, are likely to work synergistically, harming kidneys.<sup>[36,61]</sup> Thus, the use of methods that are not capable of removing such agents would be worthless and, in fact, harmful to people in these communities.

For example, the traditional water cleaning methods routinely used by the NWS&DB include size exclusion, coagulation, and chlorination, which would not remove the nephrotoxins in meaningful amounts and thus would be unlikely to prevent CKDmfo.<sup>[39]</sup> The use of such traditional methods that are incapable of removing smaller molecular weight nephrotoxins from water will provide insufficient assurances of safety to the residents of NCP and other disease-affected regions. Such approaches will not fulfil the goal of preventing CKDmfo.

#### **TECHNOLOGY**

##### **Suspended sediments**

Suspended sediment is the amount of soil and other particles in water.<sup>[21-24,45]</sup> Sediments and turbidity are dependent on the size, speed, and turbulence of the water flow. For example, fast-flowing water can pick up and suspend much more soil than can calm water. During storms, soil is washed from the stream banks into the stream. The amount that washes into a stream depends on the type of soil and terrain in the watershed and catchment areas, vegetation that surrounds rivers, and the availability and size of retention ponds.

Environmental protective measures should be taken to control excess sediments that could harm living beings in water. In addition, sediment coming into streams and reservoirs, reduces the water oxygen content and causes silting and the need for expensive dredging.<sup>[26,35,62,63]</sup> When the volume of water in reservoirs and canals is reduced because of silting, the reservoirs and canals can hold less water. This increases the risk of flooding, which has negative effects on fishing, agriculture, and recreational activities.

##### **Technologies available for the interim provision of clean water**

Remote communities are best served with the provision of potable clean water using locally available water. Water transportation via trucks and bowsers is expensive and environmentally harmful. In these situations, provision of clean water can be effectively done by means of one of two membrane-based water purification methods: RO or nano-filtration (NF) systems.<sup>[13]</sup>

The key differences of these two systems are the pore sizes of membranes, electricity and the compression pressure needs, and thus the operational costs. RO units have smaller pore sizes (and are more expensive than NF membranes), so the cut-off size for impurities in molecular masses is smaller. This requires higher operational pressures, so the overall operating costs are higher.<sup>[13]</sup> RO is used worldwide in the food and beverage industries, hospitals, and in high-end industries, such as the manufacture of electronics. These entities use multiple RO systems to generate clean water to suit their needs.

Reverse osmosis and nano purification technologies are environmentally safe, straightforward to operate with minimal training, and scalable for providing clean water to hundreds to thousands of people. However, these units need close maintenance and a significant capital expenditure. Many public health agencies and military units have large, mobile RO units for emergency use. The RO is one of the most cost-effective methods for generating a guaranteed supply of potable water for short terms or the long run.<sup>[13]</sup> Such systems can provide small- or large-scale clean water supplies within a short lead time.

To prolong the life-spans of purification membranes, it is important to pay attention to the regular maintenance of RO equipment,<sup>[13]</sup> including a proper maintenance schedule of the equipment. There are many myths discrediting this technology. However, these are mostly based on lack of understanding the fundamentals of the membrane-based water purification methods.

#### **The goal of using RO in communities**

With reference to CKDmfo, several substances have been proposed as potential causative factors,<sup>[39]</sup> including chemicals and toxins, hardness of water (i.e., excess calcium and magnesium salts), the presence of heavy metals, fluoride, plant macronutrient residues such as phosphates and nitrates, pesticides and herbicides, excess salinity or inorganic ions, and adjuncts and surfactants, and microbes in drinking water.<sup>[64-69]</sup>

All of these are effectively removed by the RO method with a single pass of inlet water through its membranes and under high pressure.<sup>[70]</sup> It is also possible that the disease is caused by a yet-unidentified substance(s). So, the scope of the purification cannot be confined to known substances and their maximum allowable limit (MAL); it must be broadened.<sup>[36,39]</sup> Purification of water based only on such concepts would not address the removal of any other potential nephrotoxins and chemicals and thus may further harm vulnerable communities.

Currently, the CKDmfo epidemiological evidence suggests the main causative factor(s) is conveyed via water; food may or may not contribute. However, what components in water cause the disease is not known.<sup>[36,39]</sup> Under these circumstances and until more information is

available, the RO method is the best option for providing safe drinking water.<sup>[13]</sup> This is particularly important because no other methods can remove such a broad spectrum of contaminants with a single step.<sup>[13,70]</sup> The use of traditional (standard) water purification systems (as used by the NWS&DB) is a bad option and unlikely to mitigate the CKDmfo.

#### **Advantages of using the RO water purification method**

In addition to removing potential toxic agents from the water, RO improves the taste by markedly reducing the hardness of the water, colour and odour, dissolved particles, and all microbial pathogens.<sup>[4]</sup> If water is remineralised after RO procedure, the taste further improves.<sup>[13]</sup> Improving the taste of water is important as a mean for encouraging people to increase their water consumption. The latter would aid in preventing dehydration and the onset of CKDmfo and possibly reverse renal impairment if it is at an early stage. Currently, the RO methodology is the most suitable and is needed for the CKDmfo-affected regions in Sri Lanka, as well as other CKDu-affected countries.<sup>[71]</sup>

The size of the RO units (clean water output/day) depends on the volume of water required for the intended population. The quality of the output water depends on the pore size of RO membranes and the quality of the inlet water, mode of operation, and proper maintenance of the unit. The mid-size RO units commonly used in village setups have the capacity to generate between 10,000 and 20,000 litres of clean water per day, which is adequate for 2,000 to 4,000 people. These units operate with two to four, 4040 standard, low-energy RO membranes (e.g., Dow Filmtec, LE 4040).<sup>[13,72]</sup>

The use of standardized RO systems, pressure-retarded osmosis, or forward osmosis systems would facilitate a reduction in the cost of replacement parts, especially membranes.<sup>[70,73,74]</sup> Another method to be considered is membrane distillation, which is driven by vapor pressure gradients using solar energy or heat-derived condensation mechanisms. The latter or the use of water ozonisation technology can overcome some drawbacks of RO.<sup>[75]</sup>

#### **PRACTICALITY**

##### **The practicality of using RO in CKDmfo-affected regions**

The temperature and the pH of water do not vary much across the NCP region, so as the impurities present in inlet water. Thus, low-cost, low-energy, standard 4040 membranes can be used in virtually all RO units in the CKDmfo-affected areas. The average rejection of water flowing through an RO purification membrane is approximately 50%. Waste water volume can be significantly reduced by using recirculation/ permeate pumps in the system.<sup>[13]</sup> The efficiency of purification of impurities in standard RO systems varies between 88% and 97%,<sup>[24,76,77]</sup> and the removal of particulate matters

approximates 100%. Some variations are expected depending on the type of membrane used, pressure generated, permeate rate, inlet water quality and temperature, and the diligence of maintenance of the RO unit.<sup>[16]</sup>

There are no known oxidizing agents, such as chlorine, present in surface or groundwater in the NCP region that can damage membranes. Nevertheless, the use of an activated charcoal pre-filter system is highly recommended in all RO water purification systems. The use of activated charcoal pre-filters removes most particles, organic moieties, odour, and colour but not heavy metals, plant nutrients, and small molecular weight toxins and inorganic matter. In addition, the use of a charcoal pre-filter increases the life-span of RO membranes.

It is generally recommended (but not mandatory) to use a second activated charcoal filter after the RO membranes to capture additional material or particles that may come through the membranes. For water supplies in certain villages, softening of water may be indicated before water is circulated through the membranes to decrease the hardness and protect membranes.<sup>[13,74,78]</sup>

#### **Other means for providing water to these communities**

The provision of clean water via the RO method is not a permanent solution for providing water to remote villages. It is only an interim measure until government, working through water authorities, provides a centrally purified pipe-borne water supply.

In the case of Sri Lanka, the NWS&DB estimates that it will take three more decades to provide such a water supply. When such a system materialises, and the water is free from toxins, the use of RO units can be discontinued; the units can be moved elsewhere or kept as backup options. At that stage, those who are receiving RO-treated water can be connected to the local network that provides pipe-borne water.

#### **Anecdotal experience**

For the past four years, for a few villagers in the NCP, the NWS&DB has been providing clean water generated through an RO unit. Each week, this drinking water is transported to these villages using diesel-powered bowsers. Although this started as a pilot project, it is expensive, unsustainable, and adds to the pollution in the region.<sup>[79]</sup>

Nevertheless, this small-scale experimental model in these villages has been shown to reduce the CKDmfo incidence by approximately 45%. Our unpublished data on pre and post provision of RO water shows very similar results; an incidence reduction of the disease by ~45%. Declining of the prevalence will take a longer time frame.

Safe, clean water must be a priority for mitigating the incidence of this deadly disease. Clean water must be provided as soon as possible to every citizen in CKDmfo-affected areas and surrounding villages. In Sri Lanka, more than two decades have passed since manifestation of this disease, yet only 15% of the people have access to safe, clean water. The plight of the people is worse in some other affected countries.

In addition to the NWS&DB, several charitable organisations install RO units at their own cost in the NCP to provide potable water for residents. Similar practices should be considered in other CKDu-affected equatorial countries. Nevertheless, it is important to coordinate these efforts to maintain the quality, safety, and sustainability of the water supply and the proper maintenance of RO units. Empowering villagers by giving them ownership of RO units is one way to achieve the sustainable goal.

#### **Unproven water purification methods will not reduce the incidence of CKDmfo**

In areas such as the NCP, the largest region in Sri Lanka that is affected CKDmfo, and in other tropical countries where non-microbial-induced polluted water is the most likely cause of diseases, one cannot justify recommending the use of any unproven technologies, even if they are much less expensive. Examples of such unproven methods suggested for use by some include the boiling of water before drinking and the use of domestic water cleaning methods, such as the use of permanganate and inefficient home water purifiers. These actions are less costly, but they are cumbersome and not effective in removing suspected constituents from water.

Some of the traditional water purification methods are adequate for the removal of hardness to make water palatable. For example, boiling water would precipitate  $\text{CaCO}_3$  and  $\text{MgCO}_3$ , reducing the temporary hardness. The use of clay pots and earthen materials reduces the contents of calcium, fluoride, and possibly some heavy metals in water.

However, these methods are much less effective than using RO processes and do not remove meaningful amounts of contaminants. The ability of clay pots, decanters, and pieces of bricks (irrespective of the type or size of brick particles) and all other earthen materials to remove hardness, heavy metals, and fluoride is limited and thus should not be relied upon or recommended.

This limited capacity is in part due to the small surface area of these materials for adsorbing ions and chemicals onto the surfaces of the material of clay and brick. This is somewhat like adsorption onto activated carbon surfaces, but the latter has several orders of magnitude of greater surface area on a weight-to-weight basis. In addition, based on how the activated charcoal is prepared, it can have absorption of compounds.<sup>[13, 36]</sup> Nevertheless, methods such as activated charcoal can be

used to complement other methods for removing unwanted and harmful components from drinking water (e.g., use as pre-filters).

Methods based on surface adsorption are much less efficient for the removal of contaminants through internal absorption into the purification material, as with ion-exchange resins. The differences in the capacity to remove ions between these two mechanisms (i.e., low capacity vs. high capacity) can be 100-fold to 5,000-fold. Consequently, the use of traditional materials alone in households should be discouraged for purifying water for drinking purposes in the CKDmfo-affected regions.

RO is the only practical and scalable method currently available that removes all potential nephrotoxins, chemicals, ions, and microbes from water;<sup>[13,35,36,44,60]</sup> it is scalable and environmentally friendly. It is easy to use and the most-cost effective method. It does not matter what component one is trying to remove: hardness, colour, odour, Na, Cl, PO<sub>4</sub>, NO<sub>3</sub>, F, Cd, As, plant nutrients, or agrochemicals, RO efficiently removes all to an acceptable level.

#### **RO-purified water does not make people sick**

Contrary to circulating myths, there is no scientific evidence to support that drinking softer water (i.e., water containing less minerals), such as water purified from RO, can cause disease.<sup>[13,78,80,81]</sup> In recent years, the use of RO-purified bottled water has markedly increased and now accounts for half the global bottled water market.<sup>[4]</sup>

For remineralisation of RO water, a calculated amount of calcium and magnesium salts is added to water.<sup>[81]</sup> More than half of RO-purified bottled water sold worldwide is not remineralised. One can easily differentiate mineralised from non-mineralised water by tasting it. There is no medical reason to remineralise water; it is done to improve the taste for marketing purposes.<sup>[80,81]</sup> Contrary to popular belief, there is no cardiovascular benefit to drinking mineralised water.

#### **DISCUSSION**

The domestic water filters used currently in the NCP and elsewhere in Sri Lanka and other affected countries are not effective in removing most toxins, agrochemicals, bacteria, viruses, or heavy metals. Many of the domestic units are fitted with filters containing small amounts of activated charcoal (too little to be effective), and the filters are of inferior quality. Such filters have a limited capacity and life-span; once such filters are saturated (usually within the first few days of use), the quality of water that comes out is the same as the inlet water. The use of such filters is a waste of funds and has no effect on reducing disease incidence, especially CKDmfo.

Contrary to the beliefs of some, none of the currently used domestic water filters or the boiling water before consumption can remove meaningful amounts of any of the mentioned toxic compounds that can harm kidneys.

These methods have only a placebo effect and thus should be discouraged. The use of such ineffective methods may increase an individual's water consumption because of the false beliefs, leading to an increased intake of toxins. This will not reduce the incidence of CKDmfo.

In addition to RO, villagers should be encouraged to use other complementary, cost-effective ways of collecting freshwater such as rainwater. However, traditional roof-based rainwater collections invariably become contaminated and thus are not suitable for drinking.

If funds are provided by the government, charities can install RO units to provide clean water in all affected regions and complete the process in a two-year period. This contrasts with the estimated more than 30 years for the NWS&DB to accomplish the task. The provision of clean water by RO units is expected to half the incidence of CKDmfo and consequently greatly reduce the disease burden in Sri Lanka and the need for renal dialysis.<sup>[36]</sup>

In summary, when there is a waterborne epidemic present, especially when the cause is unknown, as is the case for CKDmfo and CKDu in other tropical countries, the provision of RO-purified clean water is the best option; it is an ethical, rational, sustainable, and cost-effective solution.

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