Providing safe drinking water through Brackish Water Reverse Osmosis Plants: An implication for reduction of the burden of chronic kidney disease of unknown etiology (CKDu) among rural agricultural communities.

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Abstract*— *Chronic Kidney Disease of unknown etiology (CKDu) is a global health issue with an etiology in agricultural communities among the nations closer to the Equator. According to World Health Organization (WHO) recommendations, the government of Sri Lanka developed a structured national plan to combat CKDu and supply safe drinking water to the CKDu-impacted communities. Subsequently, the Sri Lanka Navy (SLN) ensured the installation of Brackish Water Reverse Osmosis Plants in appropriate locations in the national plan. The combined efforts of SLN, CKDu patients, and other stakeholders have brought a significant positive change in the lives of millions of Sri Lankans. Access to safe drinking water is a fundamental human right, and these endeavors exemplify the power of collective action in addressing pressing issues and creating a brighter, healthier future for communities impacted by water-related challenges. Therefore, the number of CKDu patients has declined since 2019. Given the success and impact of this model, it stands as a beacon of hope for other CKDu-affected countries facing similar water-related challenges. The acceptance of this approach in other CKDu-impacted regions could support the effective elimination of CKDu, thereby significantly improving the health and well-being of millions of people across the globe.

***Keywords*— Brackish Water Reverse Osmosis, Safe Drinking Water, Membranes, Chronic Kidney Disease of unknown etiology (CKDu)**

I. INTRODUCTION

Chronic Kidney Disease of unknown etiology (CKDu) is a complex disease with an etiology in farming communities in Costa Rica, Egypt (El Minya Governorate), El Salvador, Guatemala, India, Nicaragua, Panama, Sri Lanka, and Tunisia [1 & 2]. CKDu is strongly associated with hot and humid working and living environments and has become a global health issue with increasing prevalence and incidence. In addition, several epidemics of kidney disease of uncertain causative agents have emerged in Japan; and Aristolochia named them Itai-itai disease due to Cadmium and Balkan endemic nephropathy due to the release acids of Aristolochia weeds respectively. Further, causative agents of CKDu belonging to other countries remain unexplained until to date [3].

Figure 1. Global Distribution of CKDu.

The number of CKDu patients and mortality rate have increased in Nicaragua, Gua-temala, and El Salvador in the last two decades. Then, the Pan American Health Organi-zation specified that the CKD-specific mortality rates (per 100 000 population) of Nicara-gua, El Salvador, and Guatemala were shown as 42.8%, 13.6%, and 41.9% respectively [6]. According to the World Health Organization (WHO), more than 15 percent of the popula-tion aged 15-70 years in the North Central and Uva provinces in Sri Lanka are affected by CKDu. Over 22,000 deaths from the disease have been recorded; in the Anuradhapura district in the NCP in Sri Lanka since the first CKDu patient was identified in 1991 [5]. In the Indian sub-continent, by 2015, unexplained Kidney patients 34,000 were reported in Uddanam, in the coastal district of Srikakulam in Andhra Pradesh, and 4,500 were re-ported deaths. The common observations of the CKDu-impacted countries are that people involved with agricultural-based work in hot atmospheres, obtain water from dug wells, are

addicted to alcohol, and have fewer practices of occupational health [7 & 8].

Access to safe drinking water is a fundamental human right, and these endeavors exemplify the power of collective action in addressing pressing issues and creating a brighter, healthier future for communities impacted by water-related challenges [9]. Re-verse Osmosis is a major and commonly used concept to purify water in many regions of the world. However, it is an energy-intense process and contributes to Green House Gas (GHG) emissions, due to the usage of antiscalant and untreated reject water. Nevertheless, it is revealed that many countries such as Singapore, Australia, Middle-East countries, and Spain use reverse osmosis applications to treat water widely. However, it is under-stood that the operation of reverse osmosis is costly and hence difficult to use in low-er-income countries [4 & 5].

According to the WHO, possible causes of CKDu are still under investigation. How-ever, the WHO recommends several measures to control the disease, such as regulating fertilizers and agrochemicals, providing safe drinking water, better health facilities, and financial support for the victims [4]. The global health records revealed, that the number of CKDu patients has increased in all affected countries except Sri Lanka. The Government of Sri Lanka developed a national plan to combat CKDu in 2015 and conducted it as a 'Three Years' program [5]. Therefore, this study explains how Sri Lanka structured a well-planned national program to combat CKDu. Then, it describes how Sri Lanka practically worked out the program and achieved the expected outcomes of declining CKDu patients within 4 years. This research largely supports the CKDu-impacted countries to combat, and reduce this deadly disease by adopting the Sri Lankan model in a short period.

II. MATERIALS AND METHODS

The government of Sri Lanka (GOSL) developed a structured national plan to combat CKDu in three phases short-term, medium-term, and long-term Figure 2.

Short Term	**Medium Term**	**Long Term**
• Financial Support • Transport facility to dialysis process	• Manufacturing of BWRO Plants	• Supplying of drinking water through NWSDB. • Upgrading Hospital and laboratory facilities.

Figure 2. National plan to combat CKDu.

As an initial step, recognized the level of prevalence of CKDu in Sri Lanka including 8 provinces, 11 districts such as Anuradhapura, Polonnaruwa, Hambantota, Monaragala, Badulla, Kurunagala, Matale, Ampara, Mullative, Vavuniya, and Trincomalee, covering 60 Divisional Secretariats (DS) in Figure 6. Then, the Ministry of Health, Sri Lanka con-ducted a community screening for CKDu and revealed that 20,828 patients are living in the above areas. Moreover, the Ministry of Social Welfare and Empowerment carried out a survey and identified the features of CKDu and the problems associated such as the ma-jority of patients being paddy farmers with a lower level of income, limited knowledge of the disease and prevention measures, slow progression of the disease and the delay in appearance of symptoms, absence of resources to take care of patients, the social and fi-nancial downfall of the patient's families, lack of safe drinking water, and non-availability of the proper database in Figures 3, 4, & 5.

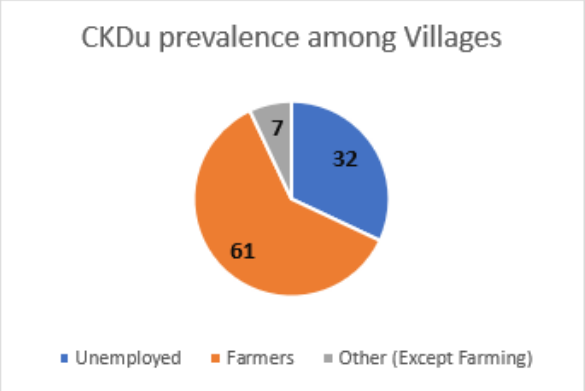


Figure 3. CKDu prevalence among Villages

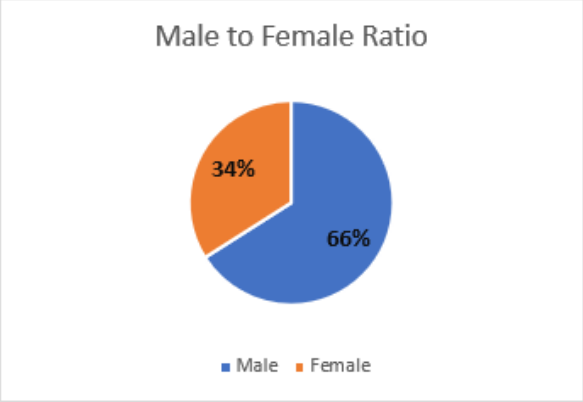


Figure 4. Male-to-Female Ratio

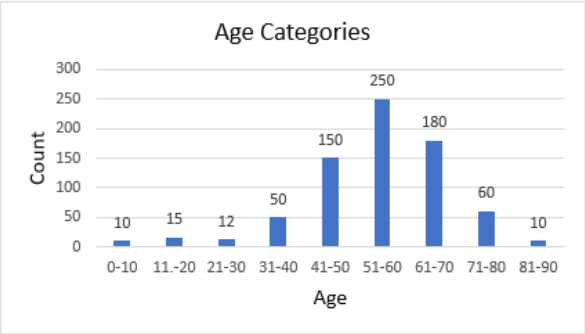


Figure 5. Age Categories

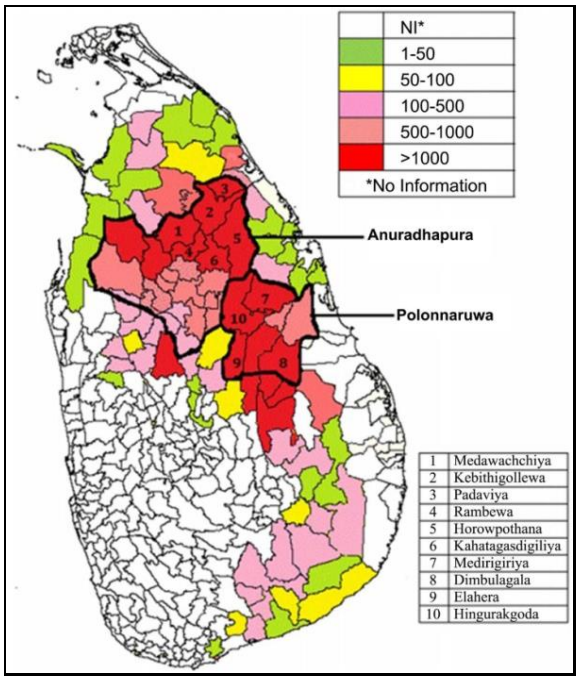


Figure 6. Vulnerable areas of chronic kidney disease of unknown etiology in the year 2016 [2]

A. Presidential Task Force (CKDu Prevention)

The Presidential Task Force (CKDu Prevention) was formed made a vision mission, and entrusted a role to play during the program in 2015. The vision clearly defined is to achieve a healthier and prosperous Sri Lanka by eradicating CKDu through a sustainable approach to en-suring safe drinking water for every citizen. The mission statement was 'Capture and exchange of knowledge, deployment of correct methodology, disease prevention, and taking care of patients and their welfare'. Then, the role consisted of preparation of national policy to prevent CKDu, proper coordination among ministries, government, and non-government organizations, sup-portive interventions in legal and policy matters, supervision and monitoring, follow-up activi-ties, and progress review in Figure 7.

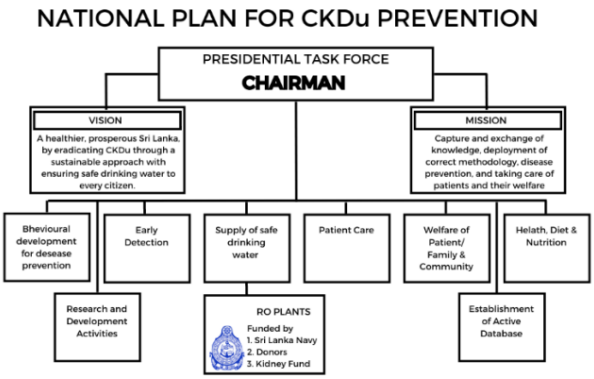


Figure 7. Structure of Presidential Task Force (CKDu Prevention)

B. Three-Year National Plan

The Sri Lankan office of WHO and Presidential Task Force (CKDu Prevention) collabora-tively conducted a three-day International Expert Consultation Conference in Colombo in April 2016 and made recommendations as essential to develop a robust surveillance system, encour-aging national/international researchers to research CKDu, reinforce the implementation of available involvements, provide social support in three levels for patients, families, and com-munity, enhance human resources in all levels, make an outline to monitor every event in CKDu and make them accountable [10 & 11]. Then, the Presidential Task Force (CKDu Prevention) de-veloped a 'Three-year national plan for CKDu and progressed in 'behavioral development for disease prevention, early detection of patients, supply of clean drinking water, patient care, the welfare of patient, family, and community, healthy diet and nutrition, the establishment of an active database, survey, research and policy preparation. Further, the National Plan was a tar-get-oriented, program carried out with the active participation of several Ministries, Departments, and Governmental and Non-Governmental organizations. This plan was carried out at the Na-tional, Provincial, District, Divisional, and Village levels. At the National Level, the Presidential Task Force and the relevant Ministries, and at the Provincial Level the Provincial Ministries and other organizations implemented the plan according to their delegated subject areas. The National Plan was executed with the support of stakeholders in districts and provincial levels, and gov-ernmental and non-governmental organizations.

C. Behavioral development for disease prevention

The behavioral development for disease prevention has had a significant impact on reducing CKDu prevalence in Sri Lanka. The program started with an awareness of the masses, unification of all institutions, adopting a proper methodology, on the possible causes of the disease, how to control the spread of disease, and preventive measures to be taken through meetings,

workshops, discussions, and case studies. In addition, adopting electronic media, print media, and social media, through dramas, and documentary movies, and conducted awareness programs of CKDu for the public. Subsequently, the Presidential Task Force introduced school-based activities, empowering village-level committees to conduct awareness programs for villages, and monitored changes in the behavioral patterns of people in Figure 8.

Figure 8. Preventive measures to be taken through meetings, workshops, discussions, and case studies

D. Early Detection

Several CKDu patients were recognized through community screening for early detection. Further, GOSL developed infrastructure facilities in Ayuruvadic clinics and conducted community screening. Moreover, the Presidential Task Force (CKDu Prevention) guided patients through technical handbooks and patient record books for screening clinics in Anuradhapura, Vavunia, and Badulla districts as an initial step and considered the target population 50,000 annually. In addition, specialist doctors, nurses, and other essential facilities, for screening are provided by the Presidential Task Force for CKDu vulnerable areas in Figure 9.

Figure 9. Community Screening in CKDu-impacted areas

E. Supply of Safe Drinking Water

WHO has recommended supplying safe drinking water to this CKDu-impacted community as a controllable measure; that leads to mitigating the prevalence of this deadly disease [10]. Then, the Presidential Task Force (CKDu Prevention) started to supply water through Bowsers, assist in setting up rainwater harvesting methods, direct establish low-cost SLN-built BWRO purification systems, extensions to the existing water supply schemes, new rural water supply schemes, rehabilitation of existing water supply schemes, large water filters and domestic water filters, monitoring and supervision of the quality of water supply to the CKDu impacted community, and development of the relevant laboratory facilities.

F. Supply Safe Drinking Water by SLN-built BWRO Plants

Sri Lanka Navy (SLN) used in-house experts to design and develop a low-cost Brackish Water Reverse Osmosis (BWRO) plant to supply safe drinking water to CKDu-impacted communities in Sri Lanka. Further, SLN researchers conducted rigorous experimental works from 2015 to date, and enhanced its efficacy and efficiency, then reduced GHG emissions through solar power integration [12 & 13]. Subsequently, SLN ensured the installation of BWRO plants in appropriate locations as per the national plan. Therefore, more than 1,000 BWRO plant locations were set up covering most of the CKDu-affected areas in the country and supplying safe drinking water to more than 2 million people free of cost in Figure 10 [13].

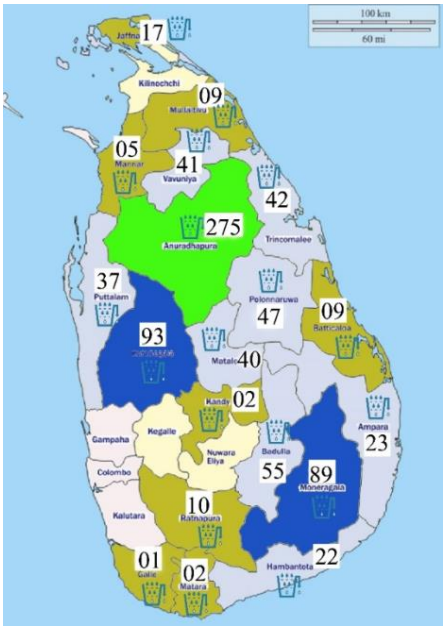


Figure 10. Locations of SLN-built Brackish Water Reverse Osmosis Plants

The capacity of the BWRO plant was defined as 10 tons/day to initiate the proposed project. SLN identified the most vulnerable locations of CKDu prevalence in Sri Lanka. This BWRO plant venture started as a corporate social responsibility (CSR) project of SLN. However, SLN got the attention of the Presidential Task Force (CKDu Prevention) diverted government funds to SLN, and fulfilled the clean drinking water requirement of CKDu-affected rural communities. SLN introduced repair teams, enhanced workshop facilities, conducted workshops to train operators, and placed naval men as operators for each BWRO station. Additionally, SLN formulated guide-lines to issue clean water for the consumers, such as 20 L per day free of cost, and instructs to maintain a log book including running hours of BWRO plant, daily backwash time, water temperature, operating pressures, utilization of antiscalant, monthly electricity bill, etc. Finally, SLN operators send

monthly returns to Naval Head Quarters. Simultaneously, SLN men forwarded monthly electricity bills to the divisional secretariat office and paid bills to the electricity board as per national budget allocations.

G. Supply of Safe Drinking Water

The BWRO plant setup comprised a raw water tank, feed pump, multimedia filter, cartridge filter, high-pressure pump, RO modules, and two flow meters. The spiral wound membrane (brand Vontron) 10.16 X 101.6 cm (4 X 40 inch) with an effective membrane area of 7.9 m2 (85 ft2) is installed with this BWRO Plant. The experiments were conducted at ambient temperature; with fully op-erational mode to get safe drinking water. The BWRO system is encompassed with Polypropylene Random Copolymer (PPR) pipes, that sustain 25 bar pressure. The feed tank is 5000 L and the feed pump operates at 3 to 4 bar pressure during the pretreatment process. Then, pretreated water was pressurized by the 12-bar multistage centrifugal high-pressure pump, and permeate was taken off from one pipe and rejection flow through another pipe to the environment. In this BWRO process, both the membranes are installed in the system, in parallel, and investigated the parameters, in Figure 11 [13].

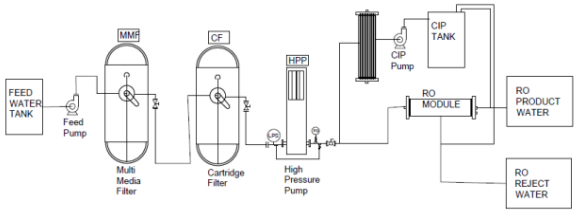


Figure 11. Schematic of Sri Lanka Navy Built 1st Version of Brackish Water Reverse Osmosis Plant [13]

H. Funding

SLN started this BWRO plant project with the Naval Social Responsibility (NSR) fund and spending 3.25 million USD, installed 260 plants in CKDu-impacted areas in Sri Lanka. Further, the Kidney Fund of the Presidential Task Force (CKDu Prevention) spent 7 million USD to install 560 BWRO plants in CKDu-affected areas. Moreover, Non-Governmental Organizations spent 2.75 million USD to install 127 BWRO plants in vulnerable locations of CKDu in Table 1.

Table 1. Funds distributions of BWRO plant installations.

Source	Number of BWRO Plants	BWRO Plant and Shelter Cost (USD)	Maintain & Monthly Electricity Cost (USD)	Operational / No-operational
Kidney Fund	580	12,500	250	Operational
Sri Lanka Navy	260	12,500	250	Operational
Non-Governmental Organizations	240	12,500	250	Operational

J. Established Medical BWRO Plants for Dialysis Units

SLN-made BWRO plants for Dialysis units in General hospitals in CKDu-impacted areas at low cost. Therefore, the government of Sri Lanka saved millions of rupees and enhanced the Di-alysis facilities for CKDu patients in Figure 12.

Figure 12. Medical BWRO Plants for Dialysis Machines

K. Financial Support

The government of Sri Lanka decided to pay Rs. 5,000 rupees to the victims every month. Further, GOSL conducted separate scholarships for school students and made a pathway to con-tinue their studies without difficulties. Furthermore, SLN and the Sri Lanka Army (SLA) carried out separate housing construction programs for victims with the financial support of donors. In ad-dition, SLN and SLA conducted another program to construct accommodation blocks for patients who were far away from Dialysis units.

L. Patient Care

Presidential Task Force (CKDu Prevention) and Ministry of Health initiated setting up Di-alysis Centers, laboratory facilities, and infrastructure facilities, uninterrupted supply of required drugs to patients, the establishment of Kidney units in hospitals, strengthening the Transplant activities, establishment of Ayurvedic clinical centers, and Amalgamation of the knowledge of the successful Ayurvedic practitioners into the clinic call network in Figure 13.

Figure 13. Patient Care

M. The welfare of patient, family, and community

Presidential Task Force (CKDu Prevention), Ministry of Defence, and Ministry of Social Empowerment and Welfare collaboratively started several projects to support low-income CKDu-impacted families of the selected districts such as self-employment projects to single-parent families of diseased kidney patients, education scholarships to Advanced Level Students of fami-lies whose parents have died of the disease, foster Parent schemes to the children of kidney pa-tients, build houses for low-income families through arm forces, strengthening of the home economy by giving Rs. 5,000 per month, the establishment of National Kidney Fund, providing of Psycho-Social counseling, and provision of Palliative Care units in Figure 14.

Figure 14. Welfare of patient, family, and community

N. Healthy Diet and Nutrition

Presidential Task Force (CKDu Prevention) initiated good practice among farmers to adopt the correct usage of fertilizer for each crop according to its nutritional requirements, and soil conditions. Further, the task force recommends importing fertilizer according to its suitability. Moreover, the Ministry of Agriculture made necessary steps to popularize Organic Farming, education of farmers on proper agricultural practices, promotion of an integrated pesticide control program, adopt traditional farming knowledge, control pesticide usage, and establishment of a sales network for unpoised healthy food products in Figure 15.

Figure 15. Healthy Diet and Nutrition

O. Establishment of an Active Database

The establishment of an active Database was coordinated by the Presidential Task Force (CKDu Prevention), and actively involved by the Sri Lanka Navy, Ministry of Health, Ministry of Agriculture, and Ministry of Social Empowerment and Welfare. Now it is witnessed and Sri Lanka has all the CKDu-related data including Geographic Information System to map the Span of Prevalence of CKDu patients at micro and macro levels, and Sentinel Sites for recording data on the disease.

P. Research and Development Activities

National Workshop on Prevention of Kidney Disease was held in Colombo on 16th De-cember 2015.

Conference on Exchange of Chinese Expertise. During this program, a State of Art Laboratory was donated to the University of Peradeniya by the Chinese Government in collaboration with the WHO Colombo Office on 15th March 2016.

The International Expert Consultative Conference was held in Colombo on 26th, 27th, and 28th April 2016.

The patronage of The Netherlands Government, the Dutch Risk Reduction Team, who are experts in water management, was invited to Sri Lanka, to study the groundwater quality and give recommendations on possible solutions to the water management in the North Central Province from 4th to 8th April 2016.

Facilitated the National Conference on Organ Donation and Transplant in Colombo on 13th August 2016.

Coordination and Facilitation of the Local Manufacture of Hemodialysis Solutions with Industrial Technology Institute and Kandy Teaching Hospital.

Sri Lanka Navy and Marine Engineering Department, Faculty of Engineering, General Sir John Kotelawala Defence University (KDU), carried out several researches since 2015 until to date to improve BWRO plants, integrate renewable energy into BWRO plants, investigate water quality in CKDu and non-CKDu areas, consuming pattern of safe drinking water, and find the causes for the disease. In addition, I am reading my

MPhil to enhance the efficiency of pretreatment process, rejected water management, substitute with herbal dosing procedure of the BWRO plant in Figure 16.

Figure 16. Ongoing research works to improve BWRO plants in the Marine Engineering Department, Fac-ulty of Engineering, General Sir John Kotelawala Defence University, Sri Lanka

Q. Study Global Implication of CKDu

Almost all the CKDu-impacted countries have many similarities such as prevalence among rural agricultural communities, tropical climate, and age of 40 to 70 male farmers predominantly affected. In addition, CKDu-impacted areas are similar and the population is also not that varying. The total death rate of CKDu is also quite similar in affected countries in Table 2 [2 & 3].

Table 2. Global Distribution of CKDu

Country	Area (km2)	Population	Period	Total Deaths
Sri Lanka	65610	22.16 millions	2013-2020	27,000
Costa Rica	51,100	5.154 millions	2011-2020	High
Egypt (Governorate Minya)	15	283,605	2010-2020	High
El Salvador	21,041	6.134 millions		22,000
India (Andhra Pradesh)	160,205	52.88 millions	2010-2020	20,000
Nicaragua	130,373	6.851 millions	2010-2020	High
Tunisia	163,610	12.26 millions	2010-2020	High
Guatemala	108,889	17.11 millions	2010-2020	13,000

III. RESULTS

Five versions of SLN-built low-cost BWRO plants developed since 2015 in Table 3.

Table 3. Global Distribution of CKDu

BWRO Plant	Year & Place	Recovery Ratio	Power Source
1st Version	2015 SLN	39-50%	National Grid
2nd Version	2016 SLN	39-50%	Solar Powered
3rd Version	2020 KDU	50%	Air Operated
4th Version	2021 KDU	75%	National Grid
5th Version	2022 KDU	75% with minerals	Solar Powered

SLN established 967 BWRO plant stations on 22nd December 2015 and supplied safe drinking water (967 X 3,000 = 2,901,000 L) per day for 2 million people in CKDU-impacted areas in Sri Lanka in Tables 4 & 5.

Table 4. BWRO plant stations in districts, villages, schools, campuses, government offices, scared places, total, consumers, populations, and percentage

	Villages	School	Campus	Hospital	Gov. Office	Sacred Places	Total	Consumers	Populations	Percentage (%)
Jaffna	9	2	3	1		2	17	30,000	626,000	
Mullaitivu	5	2		1	1		9	16,000	98,000	
Mannarama	1	1		1		2	5	9,000	114,000	
Vavuniya	28	3	2	1	2	5	41	82,000	194,000	42.7
Anuradhapura	115	48	2	5	5	100	275	540,000	954,000	56

										.6
Polonnaruwa	25	10		1	1	10	47	96,000	448,000	21.4
Trincomalee	16	7		1	1	17	42	91,000	441,000	20.6
Batticaloa	3	6					9	17,600	590,000	
Ampara	7	5		1		10	23	53,000	752,000	
Kandy		2					2	400	1,501,000	
Matale	21	17				2	40	46,000	530,000	
Badulla	26	22		1	1	5	55	128,000	895,000	14.3
Monaragala	40	27		1	3	18	89	178,000	505,000	35.2
Kurunegala	70	16	1			6	93	204,000	1,743,000	11.7
Puttalam	13	15		1		8	37	76,000	849,000	8.9
Ratnapura	5	3				2	10	18,540	1,190,000	
Colombo					1				2,480,000	
Kaluthara				1					1,296,000	
Galle	1						1		1,147,000	
Matara	1	1					2	2,800	873,000	
Hambantota	8	4		1		9	22	46,000	676,000	6.8
	394	191	8	17	15	196	821	1,506,340		

Table 5. BWRO plant stations in Navy Bases, Coast Guard Camps, Ships, Army Camps, Air Force Camps, Police Stations, Government Offices, General Locations, Mini RO Plants, Mobile RO Plants, and Total.

Stations	**Numbers**
Navy Camp	41
Coast guard	1
Ships	3
Army Ca,mp	50
Air Force Camp	2
Police	19
Civil Sec Dep	2
Hospital	17
Medical R/O	22
Gov. Office	15
General Location	822
Mini	4
Mobile	2
Total	**967**

The CKDu incidences were 6,417 in 2015 and gradually increased up to 9,174 in 2016, then 9,338 in 2017, and researched to climax 10,192 in 2018. Then, the CKDu incidences declined to 5.429 in 2019 and then further came down to 3,382 in 2020 in Figure 17 [14 & 15].

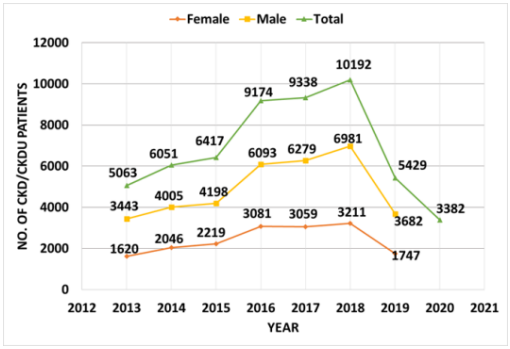


Figure 17. Number of CKD/CKDu incidences [14]

The examination of patient volumes between the year 2016, as depicted in Figure 6, and the year 2018, illustrated in Figure 18, reveals a substantial reduction in the year 2020 coinciding with the escalation in the count of Brackish Water Reverse Osmosis (BWRO) plants, as depicted in Figure 19.

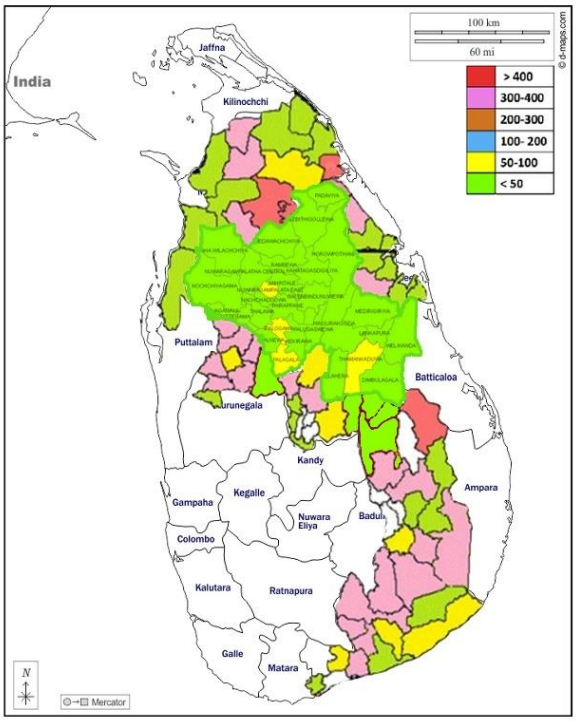


Figure 18. CKDu prevalence in Sri Lanka in the years 2019 to 2020

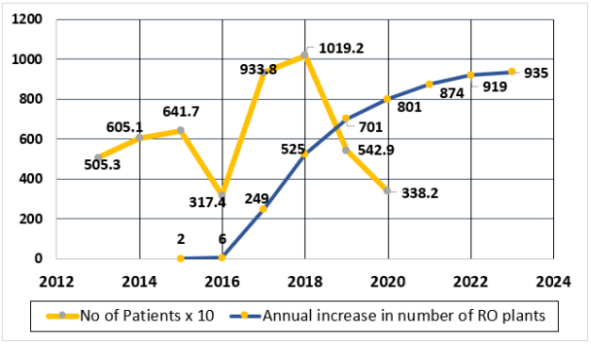
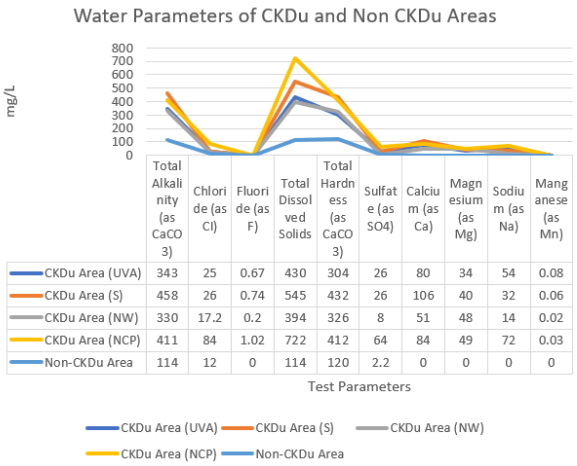


Figure 19. Impact on the number of CKDu incidents with an increment of the number of established BWRO plants

The investigation of water parameters of CKDu and non-CKDu areas in Figure 20. Then, both the water samples were collected through dug wells during the driest season. Further, Uva, Southern (S), North Central (NCP), and North Western (NW) provinces are considered as CKDu impacted areas. Subsequently, Kandy, Gampaha, Meerigama, Dompa, and Kegalle are considered as non-CKDu areas, and absolutely no CKDu patients as per records of the Ministry of Health [14].



	Total Alkalinity (as CaCO3)	Chloride (as Cl)	Fluoride (as F)	Total Dissolved Solids	Total Hardness (as CaCO3)	Sulfate (as SO4)	Calcium (as Ca)	Magnesium (as Mg)	Sodium (as Na)	Manganese (as Mn)
CKDu Area (UVA)	343	25	0.67	430	304	26	80	34	54	0.08
CKDu Area (S)	458	26	0.74	545	432	26	106	40	32	0.06
CKDu Area (NW)	330	17.2	0.2	394	326	8	51	48	14	0.02
CKDu Area (NCP)	411	84	1.02	722	412	64	84	49	72	0.03
Non-CKDu Area	114	12	0	114	120	2.2	0	0	0	0

Figure 20. Water parameters of CKDu and non-CKDu areas

IV. DISCUSSION

One of the key factors contributing to the success of these water purification plants is the consistent improvement in their efficiency over the years, starting from 2015. As technology advanced and research efforts intensified, the BWRO plants have been able to purify water more effectively and economically. This has played a crucial role in ensuring a sustainable and reliable supply of safe drinking water to those in need. Moreover, SLN has also embraced renewable en-ergy solutions to further enhance the impact and sustainability of these water supply systems. The incorporation of solar power into existing BWRO plants has not only reduced their operational costs but also made them more environmentally friendly. By tapping into renewable energy sources, the plants can operate

efficiently, even in remote areas, where access to electricity might be limited.

The Sri Lanka Navy (SLN) has achieved a commendable feat by constructing more than 1,000 BWRO plants, which have become a lifeline for 2 million people in the CKDu-impacted 20 districts of Sri Lanka. These plants are providing safe and clean drinking water, free of cost, to communities that have been suffering from water scarcity and contamination issues for years in Tables 4 & 5.

The combined efforts of SLN, CKDu patients, and other stakeholders have brought about a significant positive change in the lives of millions of Sri Lankans. Access to safe drinking water is a fundamental human right, and these endeavors exemplify the power of collective action in addressing pressing issues and creating a brighter, healthier future for communities impacted by water-related challenges. Therefore, the number of CKDu patients has declined since 2019 in Figure 17.

The decline in CKDu patients in Sri Lanka during the year 2020, as portrayed in Figure 19, can be primarily attributed to the proliferation of Brackish Water Reverse Osmosis (BWRO) plants. Notably, the most elevated patient count was recorded in 2018; however, a significant reduction ensued, with the patient population reducing to 3382 by 2020, which is an indirect result of the increased deployment of BWRO plants.

It is revealed that total alkalinity, amount of Chloride, Fluoride, Sulfate, Magnesium, Total Dissolved Solids (TDS), and Hardness of CKDu areas are significantly higher than specified limits of WHO and SLS. Then, the same parameters of non-CKDu areas are lower than the standard values in Figure 20.

V. CONCLUSIONS

In conclusion, the Sri Lankan model of constructing and efficiently operating BWRO plants has proven to be a highly successful and viable solution to combat CKDu and ensure access to safe drinking water for millions of people in CKDu-affected areas. By providing clean water to communities free of cost, the Sri Lanka Navy's initiative has set a powerful example of effective public health intervention and community-driven efforts.

Given the success and impact of this model, it stands as a beacon of hope for other CKDu-affected countries facing similar water-related challenges. The adoption of this approach in other regions could pave the way for a quick and effective elimination of CKDu, thereby signif-icantly improving the health and well-being of millions of people across the globe.

As governments, organizations, and communities unite to implement and adapt the Sri Lankan model, it will not only contribute to eradicating CKDu but also address broader issues of water security and public health. By embracing sustainable practices, investing in technology, and encouraging community involvement, we can achieve transformative results in the fight against waterborne diseases and pave the way for a healthier, more resilient future for all. The Sri Lankan model serves as a powerful reminder of the potential that lies within collective action and un-derscores the importance of collaboration and innovation in addressing global challenges.

REFERENCES

Dissanayake MCP (2020) An air operated domestic brackish water reverse osmosis plant: Economically sustainable solution for safe drinking water supply for chronic kidney disease of unknown etiology affected areas in Sri Lanka.

Dissanayake MCP (2022) Novel design of cost-effective solar powered brackish water reverse osmosis plant: A possible solution for an affordable supply of safe drinking water for the rural communities in CKDu-affected areas in Sri Lanka.

Dissanayake MCP, Ginige RS, Fernando KKN and Silva SD (2021) Chronic kidney disease of unknown aetiology in Sri Lanka: An implication of optimizing recovery ratio of brackish water reverse osmosis plant.

El Nahas AM and Bello AK (2005) Chronic kidney disease: the global challenge, The Lancet, 365(9456), 331–340.

Floris M, Lepori N, Angioi A, et al. (2021) Chronic kidney disease of undetermined etiology around the world, Kidney and Blood Pressure Research, 46(2), 142–151.

Hoy WE and World Health Organization (2016) International expert consultation on chronic kidney disease of unknown etiology.

John O, Gummudi B, Jha A, et al. (2021) Chronic kidney disease of unknown etiology in India: What do we know and where we need to go, Kidney International Reports, 6(11), 2743–2751.

Johnson RJ, Wesseling C and Newman LS (2019) Chronic kidney disease of unknown cause in agricultural communities, New England Journal of Medicine, 380(19), 1843–1852.

Noble A, Amerasinghe P, Manthrithilake H and Arasalingam S (2014) Review of literature on chronic kidney disease of unknown etiology (CKDu) in Sri Lanka.

Parameswaran S, Rinu PK, Kar SS, et al. (2020) A newly recognized endemic region of CKD of undetermined etiology (CKDu) in South India “Tondaimandalam nephropathy”, Kidney International Reports, 5(11), 2066–2073.

Ranasinghe AV, Kumara GWGP, Karunarathna RH, et al. (2019) The incidence, prevalence, and trends of chronic kidney disease and chronic kidney disease of uncertain etiology (CKDu) in the North Central Province of Sri Lanka: An analysis of 30,566 patients, BMC Nephrology, 20(1), 338.

Salinas-Rodríguez SG, Schippers JC, Amy GL, et al. (2021) Seawater reverse osmosis de-salination: Assessment and pre-treatment of fouling and scaling.

Sri Lanka Health Ministry (2020) Annual Bulletin.

United Nations Water (2019) Leaving no one behind: The United Nations World Water Development Report. World Health Organization. International standards for drinking water.

Weaver VM, Fadrowski JJ and Jaar BG (2015) Global dimensions of chronic kidney disease of unknown etiology (CKDu): A modern era environmental and/or occupational nephropathy?, BMC Nephrology, 16(1), 1–8.

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