Assess the performance of Sri Lanka Navy built Brackish Water Reverse Osmosis Plants in Chronic Kidney Disease of unknown etiology impacted areas in Sri Lanka

MCP Dissanayake[1#], NVL De Silva[2], MCH Chandrasiri[3]

Department of Marine Engineering, Faculty of Engineering, General Sir John Kotelawala Defence University, Sri Lanka

[#] dissanayakemcp@kdu.ac.lk

Abstract — The epidemic of Chronic Kidney Disease of unknown etiology (CKDu) has become a health catastrophe for over 3.6 million populations in Sri Lanka. Though the etiology of CKDu is unknown, studies revealed the synergic effects of Arsenic and Cadmium as their triggering factors. Consequently, some researchers have emphasized that the quality of drinking water might be the cause of this life-threatening crisis [5]. Sri Lanka Navy introduced a sustainable water supply concept in CKDu-impacted areas and provided safe drinking water to more than 2 million people since December 2015 through 1,000 BWRO plants [9 & 10]. As a result of that, the CKDu prevalence in Sri Lanka drastically comes down. However, the membrane fouling in several places is a major; drawback which declines permeate flux, the lifetime of the membrane, and increases transmembrane pressure (TMP). To find a suitable solution to minimize membrane fouling, a group of researchers decided to assess the performance of SLN-built BWRO plants based on the quality of product water to achieve Sustainable Development Goals (SDG) No 6. The groundwater of Dug well (water source) had raised unacceptable levels of alkalinity (94.45%), TDS (61.11%), and hardness (83.34%) as per specified standards. Subsequently, it was revealed that the Fluoride level (< 5mg/L) of the product was lower than defined standards and leading to health issues. SLN-built BWRO plants are 100% operational and supply purified water as per 'WHO' and 'SLS' standards to CKDu impacted community. Recommend to enhance the recovery ratio up to 75% and mix permeate with pre-treated water and improve the minerals level of product water Further recommends integrating Softner filter to pretreatment process when feed water has more hardness, then treat the reject water and release to the atmosphere.

Keywords — Brackish Water Reverse Osmosis, Chronic Kidney Disease of unknown etiology, Safe Drinking Water, Sri Lanka Navy.

I. INTRODUCTION

The epidemic of Chronic Kidney Disease of unknown etiology (CKDu) has become a health catastrophe for over 3.6 million populations in Sri Lanka. Though the etiology of CKDu is unknown, studies revealed the synergic effects of Arsenic and Cadmium as their triggering factors. In addition, it is revealed that Cadmium leads to diseases such as renal damage [1], hypertension [2], anemia [3], and itai-itai [4]. Consequently, some researchers have emphasized that the quality of drinking water might be the cause of this life-threatening crisis [5]. This serious health issue impacted the rice paddy farming community in the area and started with male farmers in the age group of 40 - 60 years; who were directly involved with paddy cultivation. Further, CKDu deaths are over 22,000 people in Sri Lanka since the first CKDu patient who; identified from the Anuradhapura district in the North Central Province (NCP) in 1991. Despite this fact, it has been detected among females and schoolchildren in the recent past [6].

In ancient times on words, the farming community in the dry zone of Sri Lanka had used regolith aquifer as the drinking water source. However, nature-gifted natural water resources are ruined; by reckless activities of human beings such as agricultural waste, excessive usage of fertilizers, etc. [8]. In this context, it recognizes that the conventional water treatment technologies were not enough to remove surplus dissolved minerals and possible nephrotoxins from the regolith aquifers. At that point, the Government of Sri Lanka (GOSL) conducted research on CKDu prevalence with the assistance of the World Health Organization (WHO) and recommended several measures to control the prevailing situation, such as regulating fertilizers and agrochemicals use, providing safe drinking water, better health facilities, and financial support for the victims. Therefore, the GOSL has established a Community-Based Organization (CBO) to supply safe drinking water through the application of BWRO plants in CKDu-impacted areas on a payment basis. In addition, Sri Lanka National Water Supply and Drainage Board (NWSDB) and Non-Governmental Organizations (NGOs) installed imported BWRO plants at a very high cost. However, the GOSL could not achieve the expected outcomes of this project due to several reasons; such as an insufficient wealth of the farming community to obtain safe drinking water on a payment basis, walking a longer distance to access purified water, regular membranes clogging, non-availability of skilled personnel for defect rectifications, repairing, high power consumption, and low recovery ratio. To address these challenges, Sri Lanka Navy (SLN) designed and developed a low-cost BWRO plant using its skilled personnel. Consequently, SLN introduced a sustainable water supply concept in CKDu-impacted areas and provide safe drinking water to more than 2 million people since December 2015 through 1,000 BWRO plants [9 & 10]. As a result of that, the CKDu prevalence in Sri Lanka drastically comes down in Figure 1 [11].

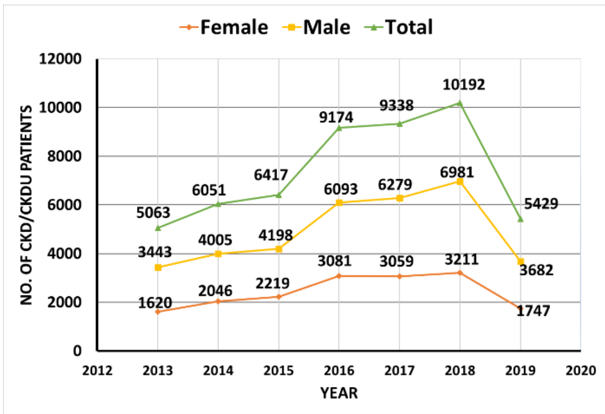

Figure 1: CKDu Prevalence in Sri Lanka up to 2019 [11]

The BWRO plant capacities were defined as 5 and 10 Tons/Day by SLN as shown in Figure 2. Consequently, it has been recognized that most of the BWRO plants contained membranes in parallel to the applications and the recovery ratio is an average of 39% - 50%, and membrane lifetime is limited to one year or a little more as per the operator's skill. SLN operators are manning BWRO plants around the clock and are ready to supply safe drinking water for consumers at any given time. Further, they are providing 20 L for family and maintaining records daily basis. Subsequently, SLN BWRO operators are carrying out daily backwashing 100% and ensuring all the operating parameters are within specified limits. Therefore, regular defects and membrane clogging are not taking place compared to CBO-operated BWRO plants [12]. In addition, monthly returns are evident that the maintenance cost of SLN BWRO plants is minimal (annually 250 USD), and issuing more than 5,000 L per day of safe drinking water to the CKDu-impacted community.


Figure 2: Brackish Water Reverse Osmosis Plant built by Sri Lanka Navy.

SLN and BWRO plants have been popular within the rural communities in CKDu-impacted areas. However, the membrane fouling in Irrattaiperiakulam village, Vavuniya District, Madawachchiya, Thalawa and Horowpothana Divisional Secretariats, Anuradhapura District, Thanamalvila Divisional Secretariat, Monaragala District, Mahiyangana Divisional Secretariat, Badulla District, and Mawathagama Divisional Secretariat, Kurunegala District a major; drawback which declines permeate flux, a lifetime of the membrane, and increases transmembrane pressure (TMP). To find a suitable solution to minimize membrane fouling, a group of researchers from the Department of Marine Engineering, Faculty of Engineering, General Sir John Kotelawala Defence University, Sri Lanka decided to assess the performance of SLN-built BWRO plants based on the quality of product water to achieve Sustainable Development Goals (SDG) No 6.

Study Area

SLN established more than 1,000 BWRO plants in Jaffna, Mullative, Killinochchi, Anuradhapura, Polonnaruwa, Kurunegala, Puttalam, Monaragala, Badulla, Trincomalee, Ampara, Hambanthota, and Matale districts as Figure 3. Then, in this study, 18 BWRO locations were selected and investigated for groundwater quality by covering the districts which are highly CKDu-impacted.


Figure 3: Sri Lanka Navy built Brackish Water Reverse Osmosis Plants in Chronic Kidney Disease of unknown etiology impacted areas in Sri Lanka.

II METHODOLOGY

Water Quality and Data Analysis

A total of 18 BWRO stations were investigated on feed water, permeate, and reject water to assess the performance of BWRO plants. Then, all water samples were tested through Industrial Technology Institutions (ITI) on physical water quality parameters (EC, pH, TDS), chemical parameters (alkalinity, hardness, metal cations, and anions) by APHA 2540 C. Total harness was calculated by equation (1). Then, the recovery ratio was calculated through equation (2 & 3).

Total Hardness (mg/L)
$CaCO_3$ = 2.497 x[Ca] (mg/L) + 4.116x [Mg] (mg/L) (1)
Recovery Ratio (%) = (Product water flow/ Feed water flow) X 100% (2)
Recovery Ratio (%) = $[(C_f - C_p)/ C_f]$ X 100% (3)
Where; C_f: Influent concentration of a specific component (mg/L)
C_p: Permeate concentration of a specific component (mg/L)

III RESULTS AND DISCUSSION

SLN built a unique BWRO plant that was fixed with two spiral wound membranes, parallel to the application. This operation, encompassed with traditional pretreatment system which consisted of a sand filter, activated Carbone filter, and 20' micron filter, but rejection water was released to the atmosphere without proper treatment. SLN operators ensure to use of antiscalants as per given instructions to minimize membrane clogging during this BWRO operation.

Normally replacement of membranes was taking place after 2 years due to skilled operators of SLN. However, the operating pressure is crucial in this BWRO operation and directly impacts the health of the spiral wound membrane. In addition, maintaining specified pressure within the membrane is a challenging task due to being unaware of the chemistry of feed water. Consequently, it is revealed that the fluctuations of operating pressures inside the membrane housing are influenced by the quality of feed water, membrane fouling, and scaling. Therefore, concise investigations were carried out on the operating pressures of BWRO plants and recognized that excessive pressures lead to severe fouling or scaling with low recovery. Further, identified that low-pressure operations (below specified standards) lead to membrane damage. In addition, it is revealed that chlorine water damages membranes regularly.

Performance Analysis

The details of feed water are in Table 1.

Table 1: General water quality parameters, Physical water quality parameters, and Chemical water quality parameters of feed water

Parameters	Ave mg/L	Maxi mg/L	Min mg/L	Requirement mg/L	Unacceptable water samples (%)
pH at 25 ^oC	7.45	8	6.82	6.5 to 8.5	
TDS	1035.95	3216	222	500	61.11
Hardness	448.5	1005	142	250	83.34
Alkalinity	342.7	510	102	200	94.45
Cl	333.5	1687	8	250	22.22
F	0.72	1.3	0.0	1	38.89
NO_3^-	8.72	23.1	0.76	50	0.0
NO_2	0.4	0.03	0.05	3	0.0
PO_4	0.0	0.0	0.0	2	0.0
SO_4	69.61	200	5	250	0.0
Ca	97.11	201	47	100	44.44
Mg	59.93	121	15	30	38.89
CN	0.0	0.0	0.0	0.5	0.0
Na	212.4	618	18	200	16.67
Fe	0.08	0.16	0.08	0.3	0.0
Cu	0.0	0.0	0.0	1.0	0.0
Mn	0.03	0.18	0.007	0.1	11.11
Zn	0.025	0.02	0.05	3.0	0.0
Al	0.08	0.16	0.07	2.0	0.0
Cr	0.0	0.0	0.0	0.05	0.0
Ni	0.003	0.01	0.004	0.02	5.5
As	0.002	0.001	0.003	0.01	0.0
Cd	0.0	0.0	0.0	0.003	0.0
Pb	0.002	0.002	0.002	0.01	0.0
Se	0.0	0.0	0.0	0.01	0.0
Hg	0.0	0.0	0.0	0.001	0.0
COD	22.44	44	5	10	27.78
C6H50	0.0	0.0	0.0	0.001	0.0
Oil & Grease	4.625	6.0	2.5	0.2	22.22

All the BWRO plants used feedwater from dug wells. To some extent, slight alkalinity is observed in this groundwater in almost all the places except Jayasumanaramaya Temple, Horowpothana, and Anuradhapura district. pH value is within WHO specified limits range (6.5 to 8.5) in all the locations. Further, it shows an unacceptable level of alkalinity (94.45%) in all the locations except the Naval Dockyard Trincomalee district. Moreover, the test report indicates an intolerable level of hardness (83.34%) in all locations except Naval Dockyard Trincomalee district, Kukulagama Monaragala district, and Dahayagala Badulla district. In addition, it shows an unacceptable level of TDS (61.11%) in most places except Kadawathrambewa Village, Madawachchiya Divisional Secretariat, Thalawa Village, Thalawa Divisional Secretariat, Anuradhapura district, Barandana Village, Mawathagama, Kurunegala district, Naval Dockyard, Trincomalee district, Kukulagma Village, Thanamalvila Divisional Secretariat, Monaragala district, Dahanyagala Village, Redeemahaliyadda Divisional Secretariat, Badulla, and Mahiyangana Town, Mahiyangana Divisional Secretariat, Badulla. According to previous studies, the lithosphere consisted of geogenic minerals such as calcite and silicate, that were major dominant of feed water [17]. Therefore, excess minerals were removed by BWRO plants and produced palatable, toxin-free, and low-mineralized safe drinking water for the CKDu impact community. All the feed water samples had very low water quality compared to specified standards.

According to the Pearson correlation coefficient, pH at 25°C, Chloride (as Cl), Total Alkalinity (as CaCO3), Fluoride (as F), Total Dissolved Solids (TDS), Total Hardness (as CaCO3), Sulfate (as SO4), and Calcium (as Ca) levels were investigated before and after purification by BWRO plants in the above-mentioned locations, and data analysis is presented in Annex 'A & B'. It was revealed that all the above elements were properly filtered as the measurements after purification showed a drastic reduction, and all the coefficient values exhibited linear correlation. The calculated values regarding the results of the BWRO plants ranged between 0.5 and 1.

However, according to Annex 'B', the Pearson correlation coefficient of Total Hardness (as CaCO3) was 0.522. A significant reduction in total hardness was observed, with the value decreasing from 1005 mg/l in Kankesanthurai (SLNS Elara) to 65 mg/l after purification. This consistent reduction in Total Hardness (as CaCO3) indicated a substantial improvement. Furthermore, a strong linear correlation between the data in Annex 'A' and 'B' was established.

Recovery Ratio

The recovery ratio is a foremost important aspect during the design of BWRO applications. Further, it is impacting to maintain efficiency and efficacy of the BWRO system and leads to retaining an economy of effort. In this context, it is revealed that the recovery ratio of SLN-built BWRO plants is maintaining a range of 38% to 47% [9&16].

IV. CONCLUSION

The groundwater of Dug well (water source) had raised unacceptable levels of alkalinity (94.45%), TDS (61.11%), and hardness (83.34%) as per specified standards. Subsequently, it was revealed that the Fluoride level (< 5mg/L) of the product was lower than defined standards and leading to health issues. SLN-built BWRO plants are 100% operational and supply purified water as per 'WHO' and 'SLS' standards to CKDu impacted community. Recommend enhancing the recovery ratio up to 75% and mix permeate with pre-treated water and improve the minerals level of product water. Further recommends integrating Softner filter to pretreatment process when feed water has more hardness, then treat the reject water and release to the atmosphere.

REFERENCES

[1]. Nakagawa, H., Nishijo, M., Morikawa, Y., Tabata, M., Senma, M., Kitagawa, Y., Kawano, S., Ishizaki, M., Sugita, N., Nishi, M. and Kido, T., 1993. Urinary β2-microglobulin concentration and mortality in a cadmium-polluted area. Archives of Environmental Health: An International Journal, 48(6), pp.428-435.

[2]. Schroeder, H.A., 1965. Cadmium as a factor in hypertension. Journal of Chronic Diseases, 18(7), pp.647-656.

[3]. Jacobs, R.M., Fox, M.S. and Aldridge, M.H., 1969. Changes in plasma proteins associated with the anemia produced by dietary cadmium in Japanese quail. The Journal of Nutrition, 99(2), pp.119-128.

[4]. Bui, T.H., Lindsten, J. and Nordberg, G.F., 1975. Chromosome analysis of lymphocytes from cadmium workers and Itai-Itai patients. Environmental Research, 9(2), pp.187-195.

[5]. Wanasinghe, W.C.S., Gunarathna, M.H.J.P., Herath, H.M.P.I.K. and Jayasinghe, G.Y., 2018. Drinking water quality on chronic kidney disease of unknown etiology (CKDu) in Ulagalla cascade, Sri Lanka.

[6]. Perera, W.P.R.T., Dayananda, M.D.N.R. and Liyanage, J.A., 2020. Exploring the root cause for chronic kidney disease of unknown etiology (CKDU) via analysis of metal ion and counterion contaminants in drinking water: A study in Sri Lanka. Journal of Chemistry, 2020.

[7]. Packialakshmi, N., Suganya, C. and Guru, V., 2014. Studies on Strychnos potatorum seed and screening the water Quality assessment of drinking water. Int. J. Res. Pharm. Nano Sci, 3(5), pp.380-396.

[8]. Dharma-Wardana, M.C., Amarasiri, S.L., Dharmawardene, N. and Panabokke, C.R., 2015. Chronic kidney disease of unknown etiology and ground-water ionicity: a study based on Sri Lanka. Environmental geochemistry and health, 37(2), pp.221-231.

[9]. Dissanayake, M.C.P., Ginige, R.S., Fernando, K.K.N. and Silva, S.D., 2021. Chronic Kidney Disease of Unknown Aetiology in Sri Lanka: An Implication of Optimizing Recovery Ratio of Brackish Water Reverse Osmosis Plant.

[10]. Dissanayake, M.C., 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. Journal of Water Resource and Protection, 12(11), p.911.

[11]. Sri Lanka Health Ministry Annual Bulletin 2019.

[12]. Indika, S., Wei, Y., Hu, D., Ketharani, J., Ritigala, T., Cooray, T., Hansima, M.A.C.K., Makehelwala, M., Jinadasa, K.B.S.N., Weragoda, S.K. and Weerasooriya, R., 2021. Evaluation of Performance of Existing RO Drinking Water Stations in the North Central Province, Sri Lanka. Membranes, 11(6), p.383.

[13]. Nyamutswa, L.T., Zhu, B., Collins, S.F., Navaratna, D. and Duke, M.C., 2020. Light-conducting photocatalytic membrane for chemical-free fouling control in water treatment. Journal of Membrane Science, 604, p.118018.

[14]. Saif, M.M.S., Kumar, N.S. and Prasad, M.N.V., 2012. Binding of cadmium to Strychnos potatorum seed proteins in aqueous solution: adsorption kinetics and

relevance to water purification. Colloids and Surfaces B: Biointerfaces, 94, pp.73-79.

[15]. Mohan, S.M., 2014. Use of naturalized coagulants in removing laundry waste surfactant using various unit processes in lab-scale. Journal of environmental management, 136, pp.103-111.

[16]. Dissanayake, M.C.P., 2022, September. Novel Design of Cost-effective Solar Powered Brackish Water Reverse Osmosis Plant: A Possible Solution for Affordable Supply of Safe Drinking Water for the Rural Communities in CKDu-affected Areas in Sri Lanka. In 15TH INTERNATIONAL RESEARCH CONFERENCE (p. 78).

[17]. Cooray, T., Wei, Y., Zhong, H., Zheng, L., Weragoda, S.K., and Weerasooriya, R., 2019. Assessment of groundwater quality in CKDu affected areas of Sri Lanka: implications for drinking water treatment. International journal of environmental research and public health, 16(10), p.1698.

ACKNOWLEDGMENT

I would like to acknowledge my wife MMA Roshini Nayana (General Manager, M/S Rashi Water) for financial support, guidance, and kind assistance throughout this national research project.

AUTHOR BIOGRAPHIES

Cmde (E) MCP Dissanayake, CEng (UK), CEng (India), FRINA, MIE (India), AMIE (SL) is currently performing as the Head of Department (Marine Engineering) and holds 2 No's patents for his research papers published so far. He is an inventor and published 15 No's publications on Brackish Water Reverse Osmosis applications, Fan Boat Building and Oscillation Water Column, and Ocean Wave Energy Converter. He was the Director of Research & Development at the Sri Lanka Navy and has received commendations on several occasions from the Commander of the Navy, HE the President of Sri Lanka for his innovation. Further, he was awarded the prestigious, Japanese, Sri Lanka Technical Award for his own developed low-cost Reverse Osmosis Plant, to eliminate Chronic Kidney Disease in Sri Lanka. Moreover, he has vast exposure to marine diesel engines and possesses a Masters's degree in Naval Engineering from Australian Maritime College, University of Tasmania, Australia.

Viraj De Silva is a Marine Engineer in the Sri Lanka Navy and presently serving as a Senior Lecturer (GR II) attached to the Department of Marine Engineering, Faculty of Engineering, KDU. He earned his BSc (DS) MarEng from KDU, an MSc in MarEng from the Naval University of Engineering, China, and an MBA(MoT) from the University of Moratuwa.

LCdr (E) MCH Chandrasiri is presently serving as a lecturer in the Department of Marine Engineering, Faculty of Engineering, KDU, and possesses a BSc Eng (Hons) in Marine Engineering degree from General Sir John Kotelawala Defence University, with a 2nd class upper merit. He is a Chartered Engineer (India) and an associate member of the Institute of Engineers Sri Lanka (IESL).