Designed A Low Cost Brackish Water Reverse Osmosis Plant: To eliminate Chronic Kidney Diseases of unknown etiology (CKDu) from Sri Lanka

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Abstract— Chronic Kidney Disease unknown etiology (CKDu) is a major catastrophe in health sector in North Central province of Sri Lanka and disable the kidney function. The main cause for the CKDu has not yet been identified, though many scientists believed that number of certain drinking water quality parameters are changed due to contamination of water sources by agricultural activities. Therefore, government of Sri Lanka is introduced a Brackish Water Reverse Osmosis (BWRO) plant to provide safe drinking water for the impacted community. However, this purified water supply project could not achieve expected standards due high cost of imported BWRO plants. Therefore, Sri Lanka Navy (SLN) engineers were carried out a feasibility study to design a low cost BWRO plant in house with utilization of local expertise to enhance the number of units in rapid time frame to enhance the supply of safe drinking water for affective community to avoid further prevalence of CKDu in Sri Lanka..

Keywords - Brackish Water Reverse Osmosis, Membrane, Chronic Kidney with Disease unknown aetiology, Safe Drinking Water, Sri Lanka.

I. INTRODUCTION

Chronic Kidney Disease of unknown aetiology (CKDu) is a complex form of disease, and disable the kidney function. Further, it will become a major health catastrophe in Sri Lanka and prevalent in the North Central Province (NCP) of the country. CKDu has become a serious health issue, that is affecting for specially for a farming community in the area. Often, the bread winner becomes a patient and this affects their livelihood. According to the world Health Organization (WHO), more than 15 percent of the population aged 15-70 years in the North Central and Uva provinces are affected with CKDu. Over 22,000 deaths from the disease have been recorded in the Anuradhapura district in the NCP since CKDu was first identified in 1991. WHO has recommended several measures to control the disease such as regulating fertilizers and agro-chemicals, the providing of safe drinking water, better health facilities and financial support for the victims (Wanasinghe, et.al.; 2018).

According to WHO recommendations, the government of Sri Lanka was decided to supply safe drinking water to affective community through Brackish Water Reverse Osmosis (BWRO) plants. Subsequently, an introduced Community Based Organization (CBO) to supply safe drinking water for impacted areas in payment basis. Further, Sri Lanka water board and Non-Governmental Organizations were played a key role to set up BWRO plants which imported from Israel and USA at very high cost. BWRO operators were coming up grievances of non-availability of skill personnel for defect rectifications and repairing, whenever plants were malfunctioning.

Sri Lanka Navy (SLN) was pioneering in Reverse Osmosis operation on board naval vessels since 1992. Further, SLN is sufficed with work shop facilities and skill personal to handle any situation, in BWRO techniques. Therefore, Director Research & Development of SLN, was conducted a feasibility study to develop a BWRO plant in-house to bring down manufacturing cost and produce more number of units to supply safe drinking water for impacted community, to ease up existing situation.

II. METHODOLOGY

The capacity of BWRO plant was defined as 10 tons/day, to initiate the proposed project. Subsequently, identified the most vulnerable locations of CKDu prevalence, in Sri Lanka.

A. Feed Water Analysis

SLN engineers were identified that the Madawachchiya area was resided with the highest number of CKDu patients' density compare to other affected areas in the country in Table 1 and Figure 1 (Ranasinghe, A.V et.al.;2019).

Table 1. Number of CKDu patients at Anuradapura and Polonnuruwa Districts (Ranasinghe, A.V et.al.;2019)

District	New CKD/CKDu patients 2012–2017 obtained from hospitals				CKD/CKDu cross sectional survey with GPS mapping (from 2012 onwards)					
Anuradhapura	Male	Female	Total	Period incidence for five year period	Number of living CKD/CKDu Patients	Total deaths	Number of deaths in CKD/CKDu patients (one year period from GPS mapping)	Point prevalence of CKD/CKDu	Proportion of deaths in CKD/CKDu patients (% for one year period)	5 year survival rate
Madawachchiya	1156	886	2042	4.35	1454	469	81	3.10	5.3	74.6
Padaviya	514	258	772	3.36	770	301	31	3.35	3.9	71.0
Rambewa	530	366	896	2.44	560	234	19	1.52	3.3	70.0
Kahatagasdigiliya	650	426	1076	2.67	678	223	28	1.68	4.0	72.1
Kabethigollawa	424	229	653	2.92	612	167	16	2.74	2.5	76.8
Horowpathana	638	366	1004	2.71	606	261	25	1.64	4.0	67.8
NPC (Nuwaragampalatha Central)	462	220	682	1.11	-	-	-	-	-	-
Maha Wilachchiya	348	157	505	2.25	-	-	-	-	-	-
Galenbinduwewa	594	314	908	1.93	-	-	-	-	-	-
NPE (Nuwaragampalatha East)	246	136	382	0.55	-	-	-	-	-	-
Nachchaduwa	125	145	270	1.06	-	-	-	-	-	-
Thalawa	453	306	759	1.31	-	-	-	-	-	-
Thirappane	244	319	563	2.08	-	-	-	-	-	-
Nochchiyagama	379	169	548	1.1	-	-	-	-	-	-
Kekirawa	237	151	388	0.65	-	-	-	-	-	-
Palugaswewa	83	48	131	0.84	-	-	-	-	-	-
Mihintale	243	138	381	1.08	-	-	-	-	-	-
Thambuththegama	253	145	398	0.94	-	-	-	-	-	-
Galnewa	215	98	313	0.90	-	-	-	-	-	-
Rajanganaya	209	81	290	0.86	-	-	-	-	-	-
Ipalogama	153	90	243	0.63	-	-	-	-	-	-
Palagala	168	73	241	0.71	-	-	-	-	-	-
Polonnaruwa										
Madirigiriya	1235	591	1826	2.78	820	281	46	1.25	5.3	71.9
Dimbulagala	842	424	1266	1.59	728	267	48	0.91	6.2	64.3
Hingurakgoda	667	443	1110	1.73	639	168	41	0.99	6.0	70.4
Elahera	711	326	1037	2.36	295	120	35	0.67	10.6	63.4
Thamankaduwa	498	274	772	0.94	-	-	-	-	-	-
Lankapura	369	219	588	1.61	-	-	-	-	-	-
Welikanda	376	180	556	1.65	-	-	-	-	-	-

Data obtained from hospitals

Data obtained from cross sectional survey with GPS mapping

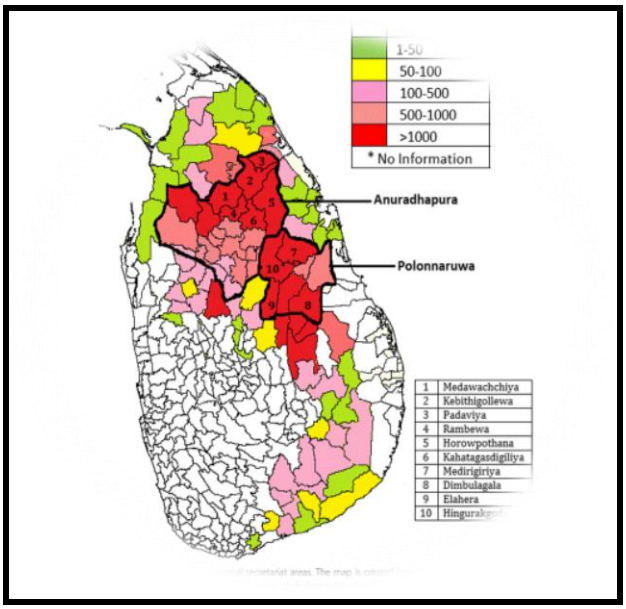

Figure 1: CKDu Prevalence in Anuradapura and Polonnuruwa Districts (Ranasinghe, A.V et.al.;2019)

B. Design procedure

Design of feed water pump

This feed pump is required to pump the feed water to multimedia filters and calculations are as follows.

Required outlet pressure – 3 bar

Gross Feed Flowrate for filtration – 2.5 m^3/hr

Capacity – 0.7457 kW (1 HP)

Design of multimedia filters

The vessel diameter is depending with standard service flow, the service water requirement and the correlation between diameter and area. The dimensions of filter vessels are calculated as follows.

Diameters of vessels

Media Quantities

Gross Feed Flowrate for filtration is most concern factor to design vessel sizes.

$$F_f = \frac{F_{fn}}{N_f} \quad (1)$$

Where, F_f is feed flow per filter

N_f is number of filter units

F_{fp} is feed flow to filtration plant

$N_f = 2$

$F_{fp} = 2.5$ m^3/hr

$F_f = \frac{2.5\ m3/hr}{2} = 1.25$ m^3/hr

Required cross sectional area for multimedia filter vessels are as follows.

$$A_f = \frac{F_f}{F_{sd}} \quad (2)$$

Where, A_f is cross sectional filtration area per filter

F_f is feed flow per filter

F_{sd} is service down-flowrate

A down flow of sand filter is one of the key factor for calculating cross sectional filtration area. Further down flow sand filters are directly impacting to separate from solid to liquid at flow rates up to about 18 m^3/h m^2 of filter area. Even though higher rate down flow filters are existing and subject to input water quality.

$A_f = 1.25/18 = 0.0694$ m^2

$$A_f = \frac{\pi}{4}(ID)^2 \quad (3)$$

Where, ID is Required Internal diameter

ID = 0.3 m

Then selected two commercially available filter vessels (12' X 52') for this application and filled with sand and active carbon up to 50% and keeping 50% free board to allow bed expansion during backwash cycle.

Design of high pressure pump

An atmospheric temperature is constant in this BWRO operation and high pressure pump purely depends with suction and discharge pressures. In addition, minimum and maximum flow rates were concerned to select the suitable high pressure pump to function BWRO plant with maximum efficiency. According to feed water parameters, the 15 bar pressure high pressure pump was chosen for this newly design BWRO application.

Pump Pressure (bar)	15
Product Water m^3/hr	40
Total Pumping Power kW	2.2

Selection of Membrane

A spiral wound 10.16 X 101.6 cm (4 X 40 inch) membranes were matched with this new design according to availability of membranes in local market, designed productivity, feed water hardness and TDS. The membrane specifications are as follows.

Capacity: 250 LPH
Type: 10.16 X 101.6 cm (4 X 40 inch) spiral wound
Make: Vontron
Effective Area: 7.9 m^2 (85 ft^2)
Material: Polyethylene
Model: 400
Operating Pressure (psi): 200

BWRO plant setup

The BWRO plant setup was comprised with 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 m^2 (85 ft^2) is installed with this BWRO Plant. The experiments were conducted at ambient temperature with fully operational mode to get safe drinking water. The BWRO system is encompassed with Polypropylene Random Copolymer (PPR) pipes, that sustains for 25 bar pressure. The feed tank is 5000 liters and feed pump is operating with 3 bar pressure for pretreatment process by overhead tank. Then, pretreated water was pressurized by the 10 bar pressure pump and permeate taken off from one pipe and rejection flow through another pipe to the environment. In this BWRO process, both the membranes are installed to the system, in parallel and investigated the parameters, in figure 2.

Figure 2: Capacity of 10 Tons/day, brackish water reverse osmosis plant developed by Sri Lanka Navy

C. Test Procedure

The operation of the BWRO plant is controlled by a control panel. Only single mode operation is comprised with control panel including operation of high pressure and low pressure safety cutouts. Both feed water pump and high pressure pump are operated simultaneously to avoid developing vacuum inside the PPR pipes. The feed water is flowing through sand filter and active carbon filter as a pretreatment process. Then, water is going through cartridge filter up to high pressure pump. Finally, water is pressuring up to 10 bar by high pressure pump and allow to flow through both the membranes and collect the product water into 1000 L tank and permit reject water flows to the environment. Whenever, product water flow is declining badly. Then, cleaning cycle is coming into the action and cut off high pressure pump and back wash the membranes and clean them.

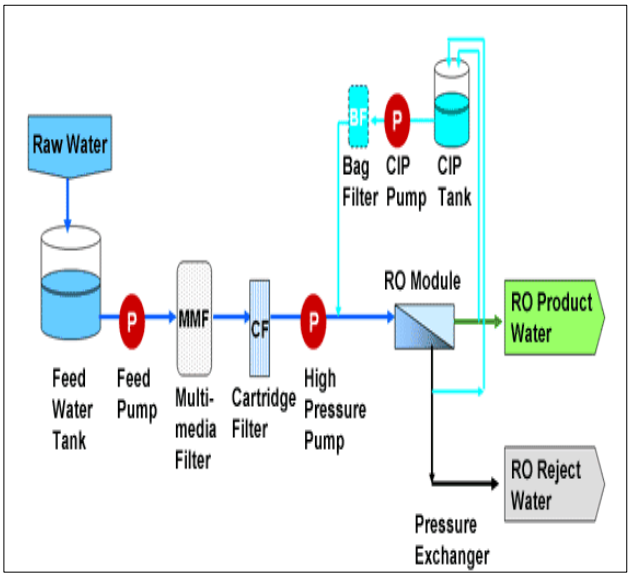

Figure 3: Schematic of Brackish Water Reverse Osmosis Plant (Almulla, A., Eid, M., Côté, P. and Coburn, J., 2003)

Table 2: Cost Comparison of Locally made Brackish Water Reverse Osmosis Plant Vs Imported Brackish Water Reverse Osmosis Plant in Similar Capacity (10 Tons/Day)

Description	Quantity	Rate (USD)	Cost for Local Plant	Cost for Imported Plant
Feed water pump (1HP, Single Phase)	1	195	195	
Sand Filter (13”X54”)	1	170	170	
Carbon Filter (13”X54”)	1	240	240	
15 L Chemical Dosing Pump	1	130	130	
40 L Chemical Tank	1	42	42	
Low pressure sensor (0-3 bar)	1	25	25	
High pressure Pump (0-15 bar)	1	650	650	
Control Panel (Locally made)	1	265	265	
20” Filter Housing	1	25	25	
20” Filter Element	1	10	10	
10” Filter Housing	1	10	10	
10” Filter Element	1	2	2	
Membrane Housing & Membranes	2	240	480	
PPR Pipes and Joints		590	590	
BWRO Skid	1	210	210	
Panel Mount Flow Meter	2	20	40	
Line Mount Flow Meter	3	25	75	
Total			**3159**	**21200**

D. Results

Five numbers feed water samples were collected from Wauniya (Irrattaperilakulam), Sri Lanka Naval Ship Pandukabaya (SLNS) (Poneewa), Madawachchiya Town (Mithreepala Central College), Dutuwewa Village and Kadawthrabewa Village and tested through Industrial Technology Institution (ITI) in Table 3.

Table 3: Tested feed water parameters in Madawchchiya area

Test	**SLS Requirement**	**Method**	**01 Vauniya**	**02 Pooneewa**	**03 Madawachchiya**	**04 Dutuwewa**	**05 Kadawathrabewa**
Colour	15 Hazen units (max)	APHA 2120 B	ND	ND	ND	ND	ND
Odour	Unobjectionable	CML 1	Objec:	Objec:	Objec:	Objec:	Objec:
Turbidity	2 NTU (max)	APHA 2130 B	ND	ND	ND	ND	ND
pH at 25^0 C	6.5 - 8.5	APHA 4500 - H^+B	7.33	7.48	7.27	7.47	7.95
Chloride (as CI)	250 mg/l	APHA 4500 CI^- B	104	71	138	89	36
Total Alkalinity (as $CaCO_3$)	200 mg/l	APHA 2320 B	510	403	498	438	358
Free Ammonia (as NH_3)	0.06 mg/l	SLS 614:2013, Appendix A	ND	ND	ND	ND	ND
Albuminoid Ammonia (as NH_3)	1.15 mg/l		0.06	0.08	0.08	0.1	0.16
Nitrate (as NO_3^-)	50 mg/l	APHA 4500-NO_3^- B	13.1	19.0	18.6	8.7	11.6
		CML/MM/02/02/019/V1.2					
Nitrite (as NO_2)	3 mg/l	APHA 4500 - NO_2^- B	ND	0.05	0.03	ND	ND
Fluoride (as F)	1.0 mg/l	APHA 4500 - FC	0.8	1.2	0.97	0.87	1.1
Total Phosphates (as PO_4)	2.0 mg/l	APHA 4500 - P B & C	ND	ND	ND	ND	ND
Total Dissolv	500 mg/l	APHA 2540 C	896	707	981	777	481

ed Solids							
Total Hardness (as $CaCO_3$)	250 mg/l	APHA 2340 C	572	403	537	423	253
Sulfate (as SO_4)	250 mg/l	Modified APHA 4500 SO_4^2E	60	45	75	50	25
Calcium (as Ca)	100 mg/l	APHA 3500 Ca - B	133	78	96	80	47
Magnesium (as Mg)	30 mg/l	APHA 3500 Mg - B	57	50.0	72	54	32
Cynide (as CN)	0.5 mg/l	CML 18	ND	ND	ND	ND	ND
Sodium (as Na)	200 mg/l	APHA 3125 B	59.3	63.3	87.4	60.0	75.9
Total Iron (as Fe)	0.3 mg/l		ND	ND	ND	ND	ND
Copper (as Cu)	1.0 mg/l		ND	ND	ND	ND	ND
Manganese (as Mn)	0.1 mg/l		0.003	0.003	0.14	0.002	0.006
Zinc (as Zn)	3.0 mg/l		0.03	ND	ND	ND	ND
Aluminium (as AI)	2.0 mg/l		ND	0.01	ND	ND	ND
Chromium (as Cr)	0.05 mg/l		ND	ND	ND	ND	ND
Nickel (as Ni)	0.02 mg/l		ND	ND	ND	ND	ND
Arsenic (as As)	0.01 mg/l		ND	ND	ND	0.002	ND
Cadmium (as Cd)	0.003 mg/l		ND	ND	ND	ND	ND
Lead (as Pb)	0.01 mg/l		ND	ND	ND	0.002	0.002
Selenium (as Se)	0.01 mg/l		ND	ND	ND	ND	ND
Mercury (as Hg)	0.001 mg/l		ND	ND	ND	ND	ND
Chemical Oxygen Demand (COD)	10 mg/l	APHA 5220 D	ND	ND	ND	ND	ND
Phenolic compounds (as C_6H_50H)	0.001 mg/l	APHA 5530 B & D	ND	ND	ND	ND	ND
Oil & Grease	0.2 mg/l	APHA 5520 B	ND	ND	ND	ND	ND

Two BWRO plants were developed and installed at Kadawathrabewa Village and Poneewa Navy camp. Then, tested the product water samples through Sri Lanka Water Board Anuradpura in Table 4.

Table 4: Product water results through Sri Lanka Water Board

Parameters	SLS Requirement	Results
Colour	15 Hazen units (max)	10
Turbidity	2 NTU (max)	0.88
pH at 25^0 C	6.5 - 8.5	7.2
Electrical Conductivity		163
Chloride (as CI)	250 mg/l	14.5
Total Alkalinity (as $CaCO_3$)	200 mg/l	50
Total Dissolved Solids	500 mg/l	48
Nitrate (as NO_3^-)	50 mg/l	8.1
Nitrite (as NO_2)	3 mg/l	0.012
Fluoride (as F)	1.0 mg/l	0.04
Total Phosphates (as PO_4)	2.0 mg/l	0.45
Sulfate (as SO_4)	250 mg/l	1
Total iron (as Fe)	0.3 mg/l	0.1
Magnesium (as Mg)	0.1mg/l	0.001

Table 5: Product water recovery

Location	Water Input (L)	Recovery (L)
Wauniya	1000	505
SLNS Pandukabaya (Poneewa)	1000	503
Madawachchiya	1000	503
Dutuwewa	1000	508
Kadawathrabewa	1000	498

E. Discussion

On completion of feed water analysis, it was revealed that the average value of TDS was 706 mg/L and average value of total hardness was limited to 419 mg/L and other parameters were within limits of SLS 614. An environmental temperature was 35 ^oC and feed water temperature was constant throughout the year in Table 3.

On completion of product water analysis, it was discovered that the results of product water were met the SLS standards and considered as safe drinking water for drinking purpose.

Water recovery of BWRO was calculated in many times and observed that recovery 50% was not sufficient compare to ground water yield at dry zone in Sri Lanka.

III. CONCLUSION

It is recommended that to improve the product water recovery up to 75% by same high pressure pump with using different method of membrane arrangements. Further, recommends to use PVC pipes with gauge 10^3 instead of PPR pipes in BWRO system to reduce the cost.

I. References

Ranasinghe, A.V., Kumara, G.W.G.P., Karunarathna, R.H., De Silva, A.P., Sachintani, K.G.D., Gunawardena, J.M.C.N., Kumari, S.K.C.R., Sarjana, M.S.F., Chandraguptha, J.S. and De Silva, M.V.C., 2019. The incidence, prevalence and trends of Chronic Kidney Disease and Chronic Kidney Disease of uncertain aetiology (CKDu) in the North Central Province of Sri Lanka: an analysis of 30,566 patients. *BMC nephrology*, *20*(1), p.338.

Almulla, A., Eid, M., Côté, P. and Coburn, J., 2003. Developments in high recovery brackish water desalination plants as part of the solution to water quantity problems. *Desalination*, *153*(1-3), pp.237-243.

Song, L., Hu, J.Y., Ong, S.L., Ng, W.J., Elimelech, M. and Wilf, M., 2003. Performance limitation of the full-scale reverse osmosis process. Journal of Membrane Science, 214(2), pp.239-244.

Stover, R.L., 2013. Industrial and brackish water treatment with closed circuit reverse osmosis. Desalination and Water Treatment, 51(4-6), pp.1124-1130.

Tamura, M. and Shinbo, A., Organo Corp, 2001. Reverse osmosis process and equipment. U.S. Patent 6,303,037.

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 Aetiology (CKDu) in Ulagalla Cascade, Sri Lanka. Sabaragamuwa University, 16(1), pp.17-27.