Refinement of Reverse Osmosis Concentrate through Bio-Char Embedded Bio-Geo Filter

T.W.L.R. Thalgaspitiya, U.L.S. Yasarathne, T.A.B. Karunasinghe, M. Vithanage and B.C.L. Athapattu

Abstract: Installation of Reverse Osmosis (RO) plants in community organizations to supply portable drinking water is an attempt in the areas with Chronic Kidney Disease of unknown etiology (CKDu) in the North Central Province in Sri Lanka. However, there have been no concerns on the brine from the RO plant, which has been directly discharged to the nearby irrigation canal or to the ground. This research was focused to investigate remedial measures for brine of ROthrough phytoremediation process using a pilot-scale surface and subsurface water construction wetlands. The field experiments were carried out focusing the community based RO water supply unit located at Medawachchiya, Sagilikanadarawa.Both surface and subsurface water Constructed Wetlands (CW) was established to measure the removal efficiency of RO concentrates through wetlands. Native soil, Calicut tile and biochar were used in proportions of 80, 17.5 and 2.5% by weight respectively as filter materials in the subsurface CWs.*Vertiver Grass* and *Scirpus Grossus* wereselected for the sub surface wetland while Water Lettuce and Water Hyacinth were as free water surface CW. The field experiment was carried out120 days for free water surface and subsurface wetlands respectively and water quality parameters were tested periodically for CKDu sensitive parameters. The results showed that the CKDu sensitive parameters such as Total Dissolved Solids, Hardness, Total Alkalinity and Fluoride were reduced up to 30, 45, 65 and 80% respectively and biochar used in the subsurface media represent major role in removing fluoride from the system. Therefore the invented bio-geo constructed wetland system is an economical and effective option for reducing high concentrations of RO reject water before discharging into the inland waters.

Keywords: Reverse Osmosis, Brine, Construction wetlands, CKDu,*Vertiver Grass*,*Scirpus Grossus*

1. Introduction

Increasing the number of chronic kidney disease unknown etiology (CKDu) patients has become an enormous problem in Sri Lanka especially in North Central Province (NCP) since the first time identification in 1990s [1]. Afterward the high incidence of CKDu shows to correlate with the presence of irrigation works and rivers that bring-in 'nonpoint source' fertilizer runoff from intensely agricultural regions [2]. In this context the chronic exposures to toxic trace elements through agro fertilizes (e.g., As and Cd) were mostly blamed for the etiology of this disease. But later on there was an investigation with keratinized matrices such as hair and nails substantial proportions of Sri Lankan population irrespective of gender, age and occupational exposure to determine the possible link between CKDu and toxic element exposures, it was observed that in patient subjects, chemical analyses of hair and nails indicated that patients were not exposed to toxic levels of arsenic or the other studied toxic elements. Therefore the early suggested causative factors such as exposure to environmental As and Cd, can be ruled out [3].

In Sri Lanka, high percentage of fluoride, hardness and high dissolved solidsnature of water is common in the dry-zone especially in NCP [4]. The high fluoride in NCP situation can be explained by the geology of the dry zone of Sri Lanka rich in gneisses, charnockites and charnockiticgneisses [5].

Eng. (Dr.) B.C.L. Athapattu, *BSc. Eng (Moratuwa), MEng.(Osaka), PhD(Osaka) CEng. MIE(Sri Lanka), Senior Lecturer,, Department of Civil Engineering, The Open University of Sri Lanka.*
Eng.T.W.L.R.Thalgaspitiya,*BTech (OUSL), AMIE (Sri Lanka), Engineering Assistant, Planning & Design Section, NWSDB, Head Office, Ratmalana.*
U.L.S. Yasarathne, *BTech (OUSL), AMIE (Sri Lanka), Engineering Assistant, Planning & Design Section, NWSDB, Anuradhapura.*
Dr. M. Vithanage,*BSc (Sabaragamuwa), MSc.(Peradeniya), PhD(Copenhagen), Senior Lecturer, Faculty of Applied Sciences, University of Sri Jayewardenepura*
Dip.Eng,T.A.B.Karunasinghe,*NDT (Civil Engineering), Engineering Assistant, Construction Section, NWSDB, Anuradhapura.*

During the last four decades, high fluoride concentrations in drinking water sources and the resultant disease "fluorosis" is being highlighted even though Fluoride is important because it is essential for the growth of human. Fluoride in drinking water has been widely-discussed in relation to CKDu.Also by increasing the ionicity of drinking water due to fertilizer runoff into the river system, redox processes in the soil, and features of 'tank'-cascades and aquifers. The consequent chronic exposure to high-ionicity in drinking water is proposed to debilitate the kidney via a Hofmeister-type (i.e., protein denaturing) mechanism [2]. Recent studies have found that the CKDu regionsare characterized by high fluoride levels in drinking water that is associatedwith higher water hardness ruling out the assumptions and hypotheses on toxic metals and metalloids [4].

National Water Supply and Drainage Board (NWSDB)is the mandated organization to provide safe drinking water for the general public in Sri Lanka and it is being their responsibility to provide good quality water for the dry zone. However, they are facing difficulties as there are no perennial rivers and many sources are seasonal. With the involvement of the government and as recommended by the WHO-SL report in 2013, they are providing treated water through bowser supply and placing and handing over the Reverse Osmosis (RO) plants for community base organization (CBO) of the relevant GND communities in endemic areas. Reverse Osmosis is the process of Osmosis in reverse and used to remove a large majority of contaminants (dissolved inorganic solids) from solution (such as water) by pushing the water under pressure through a semi-permeable membrane. The technology behind it can be used to remove particles, turbidity, cysts, bacteria, and even viruses depending upon the particle size [6]. Even though therecan be disadvantages of using RO permeate (treated water effluent from RO Plants) for long term drinking, there are easy ways to eliminate the membranes to save essential minerals or instead it is possible to add minerals before drinking.

The average purification efficiency of impurities through RO membrane is vary 90-98% (e.g., sodium, sulphate, nitrates, phosphate, fluoride, calcium) in a one-step procedure [7] and mostly the RO reject of 20-40% from inlet water volume. Hence the RO reject consists of high concentrates of TDS and other related impurities depending upon the water quality of the intake source, so that it makes exorbitant recharging directly to inland water bodies or soils as it will affected to damage their quality towards the worst. Even though we have explicit National Environmental (protection and Quality) Regulations gazette of 2008 in Sri Lanka to protect the SriLankan environment in an extraordinary manner, the RO reject is releasing to the environment for irrigation use directly or inlands as there is no proper method of disposal it to those inlands or irrigation canals still with any attention of relevant authorities. Treatment of RO rejection has been widely discussed. A study reveals an advanced oxidation processes and*Vertical Shear Enhanced Process* (VSEP) as most efficient and suitable methods for the treatment of RO reject [8]. However, another treatment for RO rejection isnot economically worth due to high labour, technology and cost involvement for the community who are performing the operation and maintenance of these RO plants by their own CBO separately plant by plant in like Sri Lanka. Thus a constructed wetland would be most appropriate to treat the RO rejection if it can withstand the concentrations.

As the natural wetlands having a higher rate of biological activities than other eco-systems, they can transfer many common contaminants of water and soils by sewers and waste in to harmless environmental products [9] and that is the main reason for using man-made wetlands; Constructed Wetlands (CW) or Engineered Wetlands (EW) to purify mostly waste waters and soils depending upon the requirement which resulted provenparallel to natural biological systems. The performance of contaminant removal from an EWis highly dependent upon the characteristics of plants, wetland physico-chemical properties of the system and contaminants themselves [10].

Depending on the contaminants and site condition the level of clean-up required and the type of plants, phytoremediation technology can be used for contaminant or removal purpose [11].Countless water quality parameters can be accumulated by most of grass and aquatic plants naturally. A 55.93% of TDS reduction were observed by Vertiver grass [12] and it was found that some minimizingthe concentration of Total petroleum hydrocarbons (TPH) in Water by *ScirpusGrossus* [13]. It was found that there is a drastic reduction in concentration of Chloride, Iron, Copper, Manganese, Lead, Fluoride, Sulphate, Nitrate, Phosphorus and Potassium can be achieve with water hyacinth [14] while that 70% of TDS reduction can be done by water lettuce [15]. Water hyacinth was most efficient for the removal of cadmium and least efficient for copper and iron in this study as BOD, DO, TSS, nitrate-nitrogen, cadmium and copper reductions ranged from 41.94-52.94%, 42.86-93.33%, 42.42-53.64%, 31.71-63.91%, 87.69-95.59% and 6.67-35.48% respectively with iron reduction occurring in the pharmaceutical wastewater only with a reduction of 90.91% [16].For sub surface flow SSF wetlands the growing media is also requiredto designing apart from free water surface (FWS) wetland systems. The depth of the media of SSF systems has ranged from 0.3 to 0.9 meters, the size of media ranges from fine gravel greater than or equal to 0.6 centimeters, large crushed stones greater than or equal to 15.2 centimeters and add a layer of compacted soil or a plastic membrane to preventing seepage to sensitive groundwater for waste water treatment process according to the EPA of US, 2002. It is necessary to select a proper media also for the CW wetland system for the selected macrophytes and in other way in SSF wetlands the plants are growing in soil under the water logged circumstances but roots and stems penetrate physically in to the soil layer by increasing pore space for easy moving the water through it.It has received attention in soil remediation and waste disposal also in recent years. The tomato plants grown in 5% biochar-amended soil showed approximately 40-fold higher biomass than that of biochar-unamended soil, whereas highly favourable microbial growth was observed in the 2.5% biochar-amended soil and also Bioaccumulation of Cr, Ni, and Mn decreased by 93–97% in tomato plants grown in 5% BC-amended soil com-pared to the biochar-unamended soil. Sequentially extracted metals in the exchangeable fraction revealed that the bioavailable concentrations of Cr, Ni, and Mn decreased by 99, 61, and 42%, respectively, in the 5% biochar-amended soil. The results revealed that the addition of BC to serpentine soil as a soil amendment immobilizes Cr, Ni, and Mn in serpentine soil and reduces metal-induced toxicities in tomato plants [17].

Based on the above literature this research was carried out to find out an amicable treatment process to purify RO rejectat Sangilikanadarawa GNDunder the Medawachciya District Secretariat (DS) division in NCP as a pilot project with the consent by the Regional Support Centre (NC) of NWSDB using both FWS and SSF wetlands with selective plants. The SSF system was integrated with native soil, biochar and the Calicut tiles as the media.

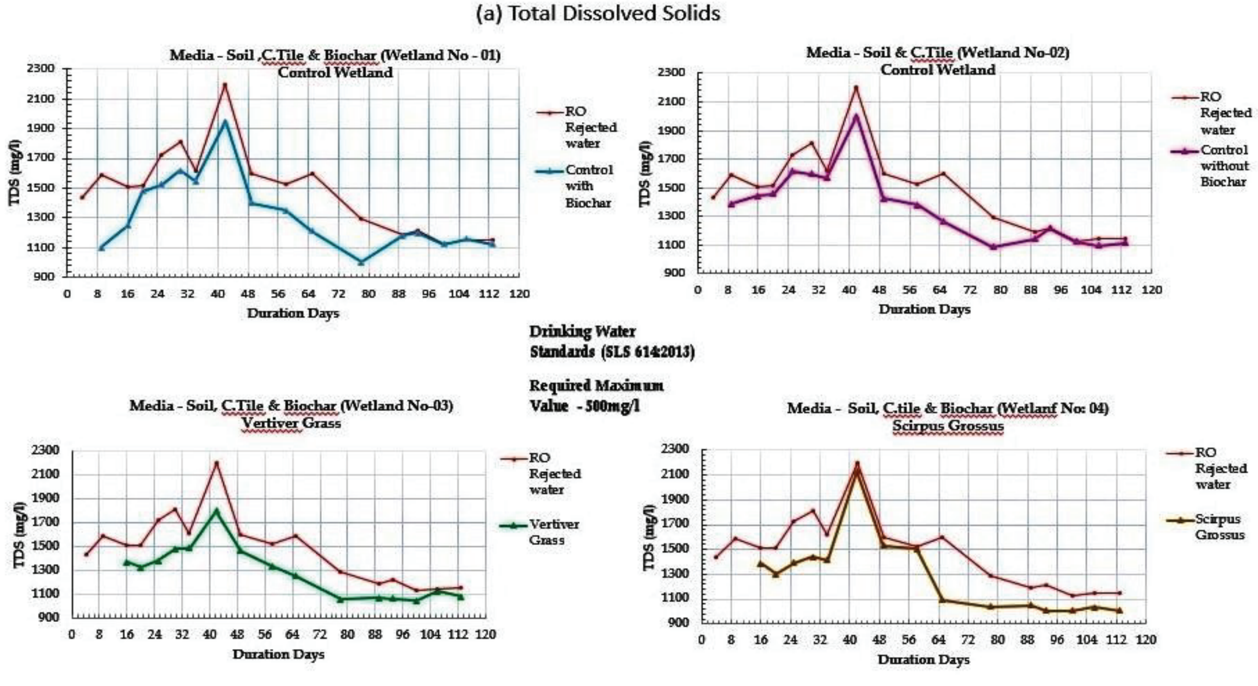
2.0 Hydraulic Design and Experimental Setup

As the Medawachchiya DS division is having more CKDu patients, it has the highest no of RO plants. When considering all RO plants in Anuradhapura and Polonnruwa districts, the high plant capacity plant is situated at Sangilikanadarawa GND in Madawachchiya area which is 20 cubic meters per day (20,000 l/day). A shallow well with a diameter of 9 m while the depth of 8 m is the water source of the plant. According to the historical data it provides water throughout the year even in drought season. The current beneficiaries of the RO plant is about 2300 including some of surrounded GNDs about 5100 l/day only for drinking and cooking purposes. In this plant all reject waters releasing at about 10 meters away from the source so that there is a great possibility to recharge the same water to the well especially in drought season. According to the tested water samples there are no heavy metals in raw water. Some chemical parameters such as Fluoride (as F^-), Total Alkalinity (as $CaCO_3$), Total Dissolved Solids (TDS), and Total Hardness (as $CaCO_3$) of reject water has exceeded the maximum required level considered to the drinking water standard of SLS 614:22013/(UDC663.6).It was a requirement to manage the land space available which is 5.0 m x 9.0 m according to the permission granted from a privet property in front of the treatment plant at Sangilikanadarawa. FWS wetlands the size of $1.00x3.21x0.35m^3$ and with the size of $6.5x0.9x.0.35m^3$ SSF wetlands were including 0.35m depth bio-geo media of 0.986 effective porosity while the sizes of control SSF as $2.85x0.90x0.35m^3$ were designed with the retention time 3-4 days together with the field experiments. Two numbers of SSF controls (CW1 & CW2), two numbers of SSF with subsurface aquatic plants (CW3 & CW4) and two numbers of FFS with floating aquatic plants wetlands (CW5 & CW6) were designed and outlined. Construction of wetland ponds was performed carefully to avoid water logging the surrounded area. Locally available aquatic plants and bio-geo media applied to treat concerned high parameters. Special concern was done on selecting plants for its sizes and roots availability when selecting plants.*Water Lettuce* (*Diya-Paradel*) and *Water Hyacinth* (*Japan-Jabara*) were placed in FWS constructed wetland while *Vertiver Grass* (*Savendara*) and *Scirpus Grossus* (*Galleaha*) were planted in rows to perpendicular direction to the direction of water flow in SSF constructed wetlands system not to allow creating direct channelling from inlet to outlet the media. Soil, Calicut tiles and Biochar were selected for Subsurface Flow wetlands. The properties of native soil were Coarse grained, poorly graded, gravely sand with little fines (Group Symbol= SP), ρ_{bulk}=1577.11(kg/m^3), w=5.01, ρ_{dry}=262.33 kg/m^3 with the analysing the test samples and Disposed Caliculttile which was collected from different places of the region made it to pieces of particle size in between 18mm to 25mm were used. The biochar was a produced by pyrolyzing Gliricidia biomass at 900 °C in a closed reactor as a byproduct of generating energy at the Dendro power plant at Labunoruwa, Anuradhapura which is characterized and having Surface area of 714 m^2/g (Laboratory results, NIFS). The required mediaproportions were tested experimentally tested for SSF system design and used the mix proportion of soil, Calicut tile and Biochar as 80, 17.5, 2.5% respectively.

Table 1 Maximum and Minimum % reduction in different wetland types (Source: Athapattu et al., 2017)

Wetland type	TDS % reduction		Alkalinity % reduction		Hardness % reduction		Fluoride % reduction	
	Min	Max	Min	Max	Min	Max	Min	Max
Control with BC (CW1)	2.1	17.5	5.4	60.9	5.6	47	51.6	72.6
Control No BC (CW2)	3	12	0	28.3	0	31.3	0	50
Vetiver grass (CW3)	8.2	20.2	27.4	41.8	29.4	37	20.9	82.5
Scirpus grossus (CW4)	8.3	20.6	29.7	42.3	14.4	39.8	25	84.3
Water lettuce (CW5)	1	6.6	2.1	19.6	8.2	22.5	4.8	32.5
Water hyacinth (CW6)	1.2	22.8	1.3	22.8	5.5	21.5	0	15

3.0 Results and discussion


(a) Total Dissolved Solids

Media - Soil ,C.Tile & Biochar (Wetland No - 01) Control Wetland

Media - Soil & C.Tile (Wetland No-02) Control Wetland

Drinking Water Standards (SLS 614:2013)

Required Maximum Value - 500mg/l

Media - Soil, C.Tile & Biochar (Wetland No-03) Vertiver Grass

Media - Soil, C.tile & Biochar (Wetlanf No: 04) Scirpus Grossus

Figure 1 Performance of SSF Wetlands for the reduction of Total Dissolved Solids

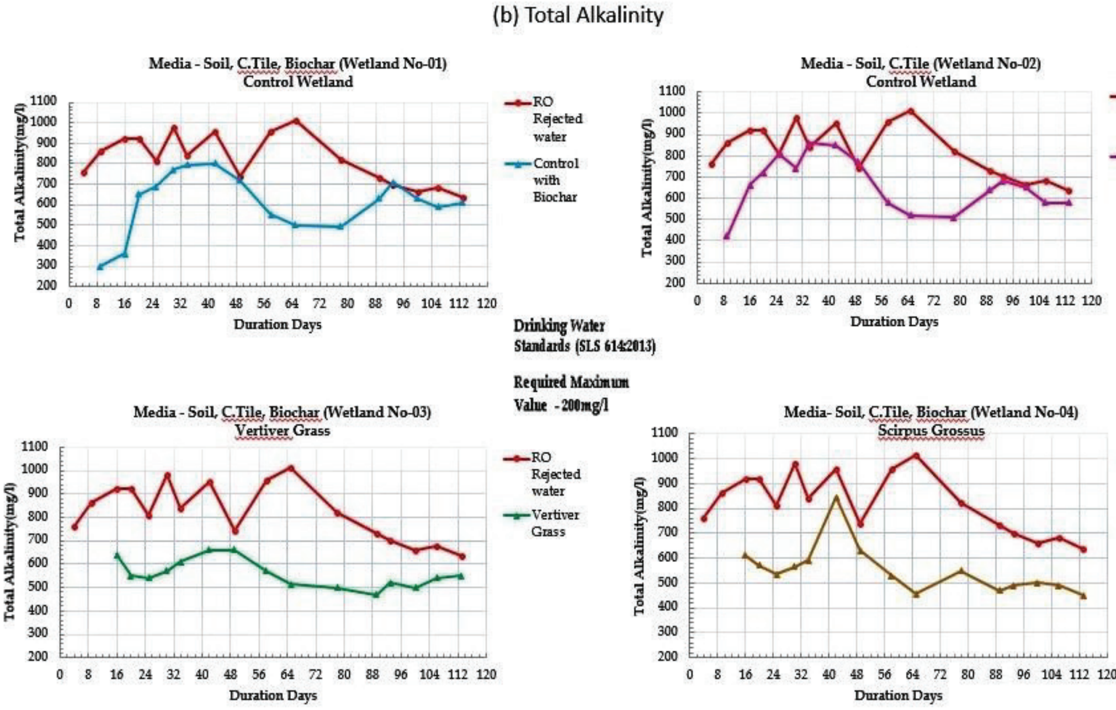


Figure 2 Performance of SSF Wetlands for the reduction of Total Alkalinity

The water quality analysis was carried out for concerned chemical parameters namely Total Dissolved Solid (TDS), Total Hardness (as $CaCO_3$), Total Alkalinity (as $CaCO_3$) and CW6 (with *Water hyacinth*) is started after 4 days of placing plants to the wetlands. According to the test results given in Table1 it shows considerable reduction of all parameters at the beginning. But the percentage reduction is becoming less when time passing and it is obvious due to the reach of the maximum sorption capacity. For Hardness it gives still better results from both the plants with compared to other results. The lifecycle

Fluoride (F^-) to check the performance of constructed wetlands. Water quality analysis for FWS control wetlands; CW5 (*Water lettuce*) and

achieved around 45 days and therefore it is necessary to replace with new plants. According to the Observations it can be seen that the concentrations of subjected water quality parameters are reducing with respect to the concentrations of the inlet which is RO reject water. However the concentrations of RO reject was changing in every testing date which can be accepted as the raw water quality of the RO plant water source water quality changes.

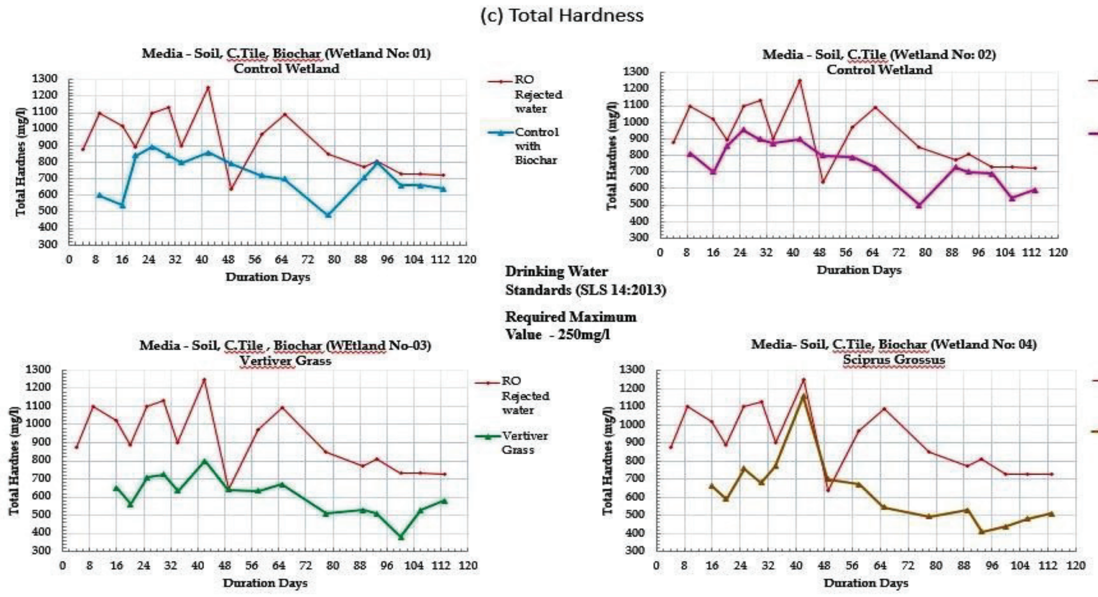


Figure 3 Performance of SSF Wetlands for the reduction of Total Hardness

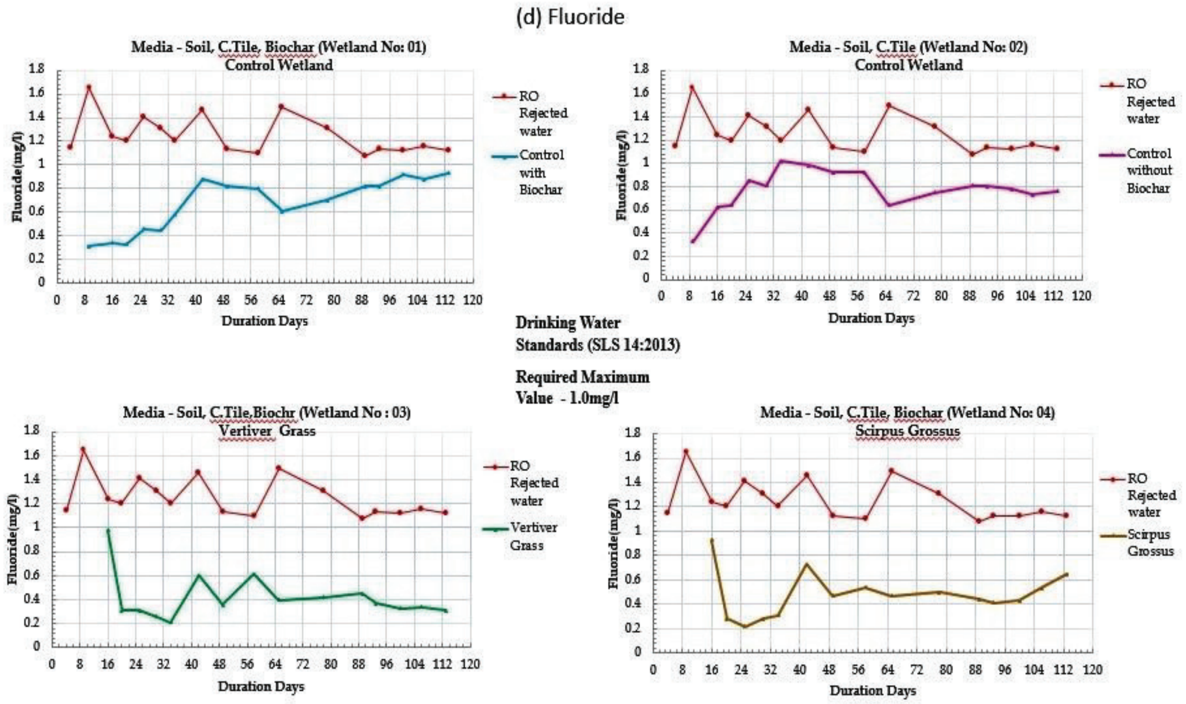


Figure 4 Performance of SSF Wetlands for the reduction of Fluoride

Water quality analysis for SSF wetlands with plants was started after 16 days of planting the selected plants as to allow considerable period for start growing those with the particular SSF wetlands with *Vertiver Grass* and *Scirpus Grossus*which is very high performance. In thestarting the CW1 (control with biochar) shows high efficiency of removing all 4 parameters than other wetlands specially compared with the CW2 (control wetland with no biochar). But after 88th day the TDS, Total Hardness and Total Alkalinity reducing capacity seemsvery less except the reducing performance of fluoride. Concentration of total Alkalinity in Figure 2 noted high valueson 64th day and the concentration of TDS on 43rd day in Figure 1.According to the graphs shown in Figure 3, it shows that the level of Hardness concentration became low till it reaches 48th day andafter wardsCW1 and CW2wetland systems; controls were unable to lowering than that within the system as it balancing the in and out concentrations while CW3 (with *Vetiver grass*) and CW4 (with*Scirpus grossus*)performing high removal capacity on their system. Altogetherit seems high reducing capacitystarted in between 48-88th day for TDS, Alkalinity and Hardness as well for combined systems which involves biochar based media and the subsurface plants but still indicating the reduction capacity with a variable reduction capacity in all SSF constructed wetlands other than CW2 and CW3. Fluoride reduction shows very high in media while SSF wetlands started by 4 days. According to the graphs shown in Figure 1 to 4, it clearly shows that the reduction of all parameters for Figure 4 with SSF combined with plants and the performance is still continuing on 112th day with slight decreasing in CW4 and still increasing with CW3.

Reducing of all parameters gives higher value in control with biochar than control without biochar and boththe control wetland performances are moving towards less reduction percentage with respect to the RO reject concentrations by reaching 112th day than the beginning. The best performance is given for fluoride removal among all 4 SSF wetland systems. The system of SSF wetland with the plants demonstrated the reduction performance contributes not only the biochar, Calicut tile and native soil mixed media but also the plant roots and their shoots and it may possible the contaminant removal is manly governed by various biological and physicochemical factors including microbial activity, uptake by plant species, sedimentation, flocculation, precipitation, adsorption, complexation, oxidation and reduction and cation and anion exchange [18]. With the summarised results showed that the CKDu sensitive parameters such as Total Dissolved Solids, Hardness, Total Alkalinity and Fluoride were reduced up to 30, 45, 65 and 80% respectively as the biochar represent mainly in removing fluoride from the system. A variety of Oxygen-containing functional groups are contained in Biochar such as –COH and –COOH [19, 20]. Those functional groups contain long pairs of electrons andprotonated functions facilitate to absorb hydrated fluoride ions [21]. The Biochar may play a major role in removing fluoridefrom the system which may be due to the existing and adsorbed K^+, Ca^{+2}, Mg^{+2}, etc. on the biochar surface via chemisorption [22]. Therefore it is concluded that the biochar embedded bio-geo filter media is the most effective method for refinement of ReverseOsmosis Concentrate for water quality parameters selected above, especially fluoride and Hardness other than removal of Cr, Ni, andMn and help improving plant growth [19].

4. Conclusion

Four types of bio-geo constructed wetlands under Free Water Surface (FWS) and Subsurface Flow (SSF) were established and operated. *Vertiver Grass* and *Scirpusgrossus* were carefully selected for the SSF constructed wetlands (for CW3 and CW4 respectively) while *Water Lettuce* and *Water Hyacinth* were chosen for SSF constructed wetlands (for CW5 and CW6 respectively). Two controls were selected for SSF constructed wetlands as with biochar and without biochar. The cost incurred to construct this system for both SSF and FWS wetlands was approximately SLR 60,000/- with the locally available materials which is considerably very low with other purification systems. This proves that the system seemed to be workable and effective with a community participation by means of the awareness programs to achieve successfully for recover the minimum mineral requirements and a simply achievable solution for the RO concentrate before releasing to the environment at CKDu affected areas in Sri Lankaconcurrentlywhen introducing and placing the RO plants.

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