Soil contamination by direct disposal of Reverse Osmosis reject water onto the ground in the Chronic Kidney Disease of unknown etiology (CKDu) prevalent areas

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ABSTRACT: Reverse Osmosis (RO) units have been installed in areas where Chronic Kidney Disease of unknown etiology (CKDu) prevails to provide good quality drinking water. At present, RO reject water is directly discharged onto the ground, which may cause potential soil contamination. This research investigated the possibility of soil contamination and their levels due to direct disposal of RO reject water onto the ground. Water samples (RO permeate and reject) and soil samples from disposal sites and reference sites were collected and analyzed for various constituents (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, F^{-}). RO reject water showed high concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and F^{-} ions. Analysis of soil samples from RO reject water disposal sites showed high concentrations of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} compared to the reference sites and optimum levels for healthy growth of plants. This was mainly attributed to the direct discharge of RO reject water rich in such constituents onto the ground. In conclusion, soil contamination was observed due to direct discharge of RO reject water onto the ground, which may lead to reduction of soil fertility and retarded plants growth in the long run.

1 INTRODUCTON

Chronic Kidney Disease of unknown etiology (CKDu) has become a serious health issue in some parts of Sri Lanka, mainly in the North Central Province [NCP] (Dharma-wardana, 2014, Abeygunasekera & Wickremasinghe, 2012). The exact causal factors for CKDu have not yet been clearly identified. Among many potential factors suggested by previous studies, presence of heavy metals, fluoride and pesticides in the drinking water have been suspected to be some of the main causes of CKDu (Wanigasuriya, et.al., 2012, Jayasumana, et.al., 2014). Providing good quality drinking water is considered as a solution to minimize the CKDu prevalence (Paranagama 2014).

Reverse Osmosis (RO) technology has been introduced in the CKDu affected areas as a means of water treatment for providing good quality drinking water to the CKDu affected communities. RO treatment is adopted to remove various constituents such as metal ions (Noble, et.al., 2014) and anions (Dissanayake, 2012, Jayasumana, et.al., 2014) that are present in excess amounts in the raw water. RO treatment generates reject water (effluent) which contains the impurities and contaminants that have been filtered out by the RO membrane. Direct discharge of the RO reject water onto the surrounding ground surfaces is the common practice of disposal of the effluent at all RO units that are operating in the CKDu affected areas in the NCP.

The RO reject water would comprise various contaminants that have been included in the raw water filtered through the RO membrane and high concentration of contaminants are expected to be present in the reject water. Hence, direct disposal method of the RO reject water is receiving attention as it may lead to some negative environmental impacts. When the RO reject water is directly discharged onto the ground, contaminants present in the water could be accumulated in the soil and leached out to surrounding water. In the long run, this could cause severe contamination problems in the soil and water. Soil fertility could be decreased and there is a possibility that elevated ion levels lead to toxicity effects for plants. The consequences of the direct disposal of the RO reject water onto the ground have not yet been properly investigated. Therefore, this study aimed at investigating the effect of the direct disposal of RO reject water onto the ground and its potential environmental impacts.

2 OBJECTIVES

Main objective of this research was to investigate potential contamination of soil due to direct disposal of RO reject water onto the ground. In order to achieve this objective, it was necessary to estimate:

- The constituents (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, F^{-}) levels present in Raw water, RO treated water (permeate) and RO reject water
- The constituents (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, F^{-}) levels present in the soil strata to which RO reject water was directly disposed to.

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3 METHODOLOGY

3.1 *Sample collection*

Five commercial RO plants which are located within the NCP were selected for the study. Figure 1 shows the geographical distribution of the RO plants and respective sampling locations.

Fig. 1 Location map (1-Arunagama, 2-Ranpathvila, Kahatagasdigiliya, 3-Ranpathvila, 4-Rambewa, 5-Thalawa, Jayaganga)

3.1.1 *Water samples*

Raw water, RO permeate and RO reject water samples of five locations were analyzed separately for selected constituents (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, F^{-}) to investigate the levels of respective constituents present in each sample.

3.1.2 *Soil samples*

Soil samples from five locations where RO reject water was directly discharged as well as reference locations located upstream of each RO plant were collected and analyzed for selected constituents (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, F^{-}). These levels would assist in understanding the potential soil contamination due to disposing of RO reject water directly to the ground. Soil samples were taken at 25 mm and 300 mm depth at both discharging and reference points in each location as there is no evidence available as to how deep the soil contamination could occur. Reference soil sample was taken upstream with respect to the discharging point thus RO reject water has no impact. All soil samples were collected separately, sealed and transported to the laboratory.

3.2 *Chemical analysis*

3.2.1 *Water samples*

A fixed volume (100 ml) from each water sample was taken; 25 ml conc. HCl was added and digested at 110ºC for about 1-1.5 hours until the sample volume reduced to half. Volume of the digested samples was made up to 100 ml using distilled water.

3.2.2 *Soil samples*

Preparation of soil samples for ions analysis was carried out based on ISO 11466:1995, Soil quality-Extraction of trace elements soluble in aqua regia (last reviewed and confirmed in 2016). About 10 g of each soil sample was oven dried at 105ºC for 1 hour. Oven dried samples were crushed and grounded and 1 g of prepared sample was taken for analysis. Concentrated HCl (15 ml), Conc. Nitric acid (5 ml) and distilled water (15 ml) was added to 1 g of soil. Sample was digested at 100ºC about 1 hour until volume reduced to half. Digested samples were filtered through filter papers and the volumes of the samples were adjusted to 100 ml using distilled water.

A Standard series was prepared using high purity chemicals of each constituent of concern. The digested samples were analyzed for Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} using the Flame Atomic Absorption Spectrometer (FAAS) and F^{-} using SPADNS colorimetric method. When necessary, the digested samples were diluted accordingly so that the unknown concentration of the constituents falls within the calibration range.

4 RESULTS AND DISCUSSION

4.1 *Analysis of water samples*

Table1. Electrical conductivity (EC) and pH

Location	Raw water		Permeate		Effluent	
	EC (µS)	pH	EC (µS)	pH	EC (µS)	pH
1	677	7.74	149.3	7.77	888	7.88
2	931	7.49	84.7	7.91	2100	7.71
3	1091	7.48	76.5	7.68	1710	7.63
4	2280	7.26	216.0	7.81	2440	7.45
5	1234	7.36	109.7	7.85	1447	7.55

The EC showed higher values in RO reject water than EC in raw water and permeate (Table 1). Higher conductivity in RO reject water indicated the presence of higher ions concentrations. Sri Lankan Standards (SLS) specifies that EC should be less than 2250 µS in the effluent if it is to be discharged to the land for irrigation purposes (SLS-776, 2011).

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Table 2. Ion concentrations detected in water samples

Location	Water sample														
	Raw water (ppm)					RO Permeate (ppm)					RO reject water (ppm)				
	Na^+	K^+	Ca^{+2}	Mg^{2+}	F^-	Na^+	K^+	Ca^{+2}	Mg^{2+}	F^-	Na^+	K^+	Ca^{+2}	Mg^{2+}	F^-
1	82.01	0.168	11.55	46.44	1.592	11.21	0.152	7.162	1.637	0.212	191.7	0.291	45.43	52.30	1.963
2	81.31	0.581	12.63	48.81	0.663	6.27	0.028	2.273	0.383	0.186	169.7	0.982	53.78	105.4	2.865
3	72.36	0.577	32.47	28.35	0.424	5.57	0.108	7.258	0.773	0.265	115.9	0.613	90.12	77.32	1.565
4	117.8	0.456	111.09	67.30	4.562	19.56	0.342	3.534	0.905	0.027	167.2	0.494	170.4	98.56	5.013
5	179.1	0.101	15.75	28.22	3.246	21.72	0.073	1.596	2.846	0.641	222.3	0.185	21.68	83.12	3.952

Locations 1,2,3,5 satisfy the above criteria for irrigation. Location 4 showed slightly higher EC than the SLS specified value. Table 2 summarizes the ion concentrations detected in raw water, RO permeate and RO reject water collected from all locations.

At all locations, Mg^{2+} and Ca^{2+} levels in the permeate (Table 2) were less than highest desired levels as specified in Sri Lankan standards for drinking water; K^+ is not specified, Mg^{2+}=30 mg/l, Ca^{2+}=100 mg/l (SLS 614, 2013). Na^+ level in Location 5 (Table 2) was higher than 20 ppm, which is the highest desirable level as specified in WHO guidelines for drinking water (WHO, 2011). F^- level should be within 0.5 ppm – 1.5 ppm according to WHO drinking water standards (WHO, 2011) and this criterion was satisfied only in Location 5 (Table 2). On the other hand, F^- level should be 1 ppm according to Sri Lankan Drinking water standards (SLS 614, 2013); F^- was removed beyond the required minimum level at all RO plants studied.

4.2 *Analysis of soil samples*

Figures 2, 3 and 4 present the variation of K^+, Ca^{+2} and Mg^{+2} ion concentrations, respectively, of soil samples collected from reject water disposal sites at 25 mm and 300 mm depths as well as respective reference locations.

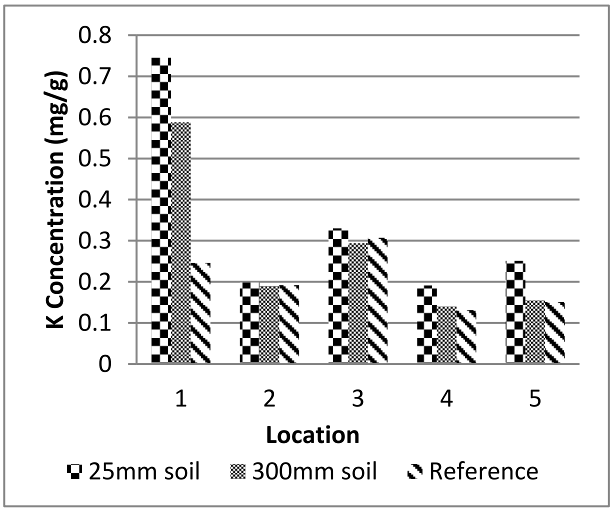

Fig. 2 Concentration of K^+ present in soil (mg/g)

Soil from reference locations showed lower ion concentrations compared to the respective ions levels detected in RO reject water disposal sites clearly indicating introduction of excess ion levels to soil from RO reject water disposal. Concentrations of constituent ions of concern were expected to be high in the top soil layers as a result of direct discharge of RO reject water onto the ground surface.

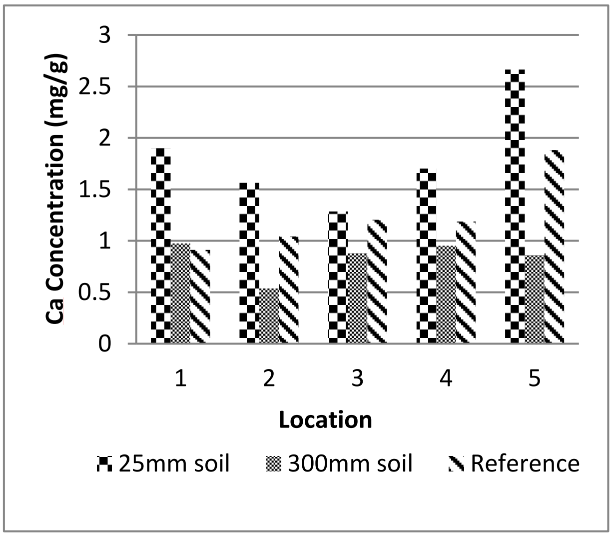

Fig. 3 Concentration of Ca^{2+} present in soil (mg/g)

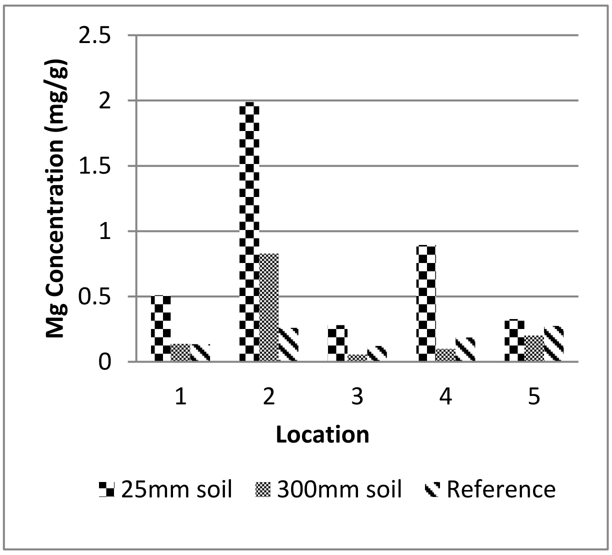

Fig. 4 Concentration of Mg^{2+} present in soil (mg/g)

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Results of analysis of soil samples showed a deviation from the expected trends. Only K^+, Ca^{+2} and Mg^{+2} showed higher values at 25 mm layer than the respective ions concentrations detected from soil at 300 mm layer. It is likely that some of the ions would be adsorbed by soil particles at the top soil surface and be retained by the top soil (Fig.3 and Fig.4) without leaching them to deeper layers.

Figure 5 shows the variation of Na^+ ion concentrations of soil samples collected from reject water disposal sites at 25 mm and 300 mm depths as well as the reference point. Although Na^+ concentration was very high in the reject water of all locations (Table 2), Na^+ content at some locations showed lower levels compared to the respective reference site (Table 2 and Fig.5). This could be attributed to the possible washout of Na^+ ions due to continuous discharge of the RO effluent.

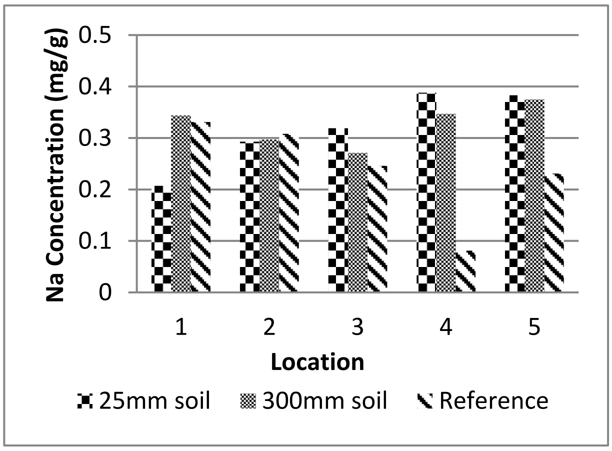

Fig. 5 Concentration of Na^+ present in soil (mg/g)

Figure 6 shows the variation of F^- ion concentrations of soil samples collected from reject water disposal sites at 25 mm and 300 mm depths and the reference point. In general, all locations contained high F^- levels and the F^- levels at the reject water discharging locations were approximately equal to the respective reference points. High F^- levels detected in reference sites shows that soil contamination by F^- due to RO effluent discharge could be minimal.

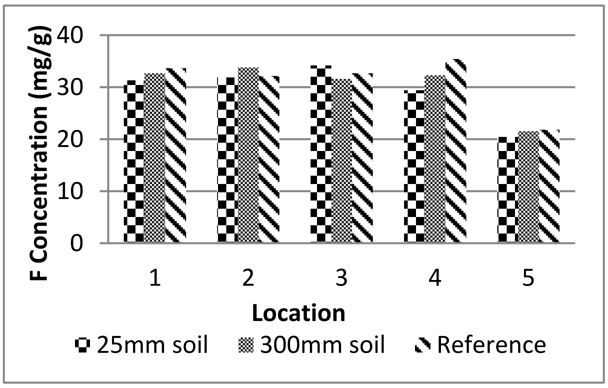

Fig. 6 Concentration of F^- present in soil (mg/g)

Table 3. Optimum constituent levels for Banana and Mango cultivation (Daniells & Armour, 2008)

Parameter	Optimum level desirable for Banana growth	Optimum levels desirable for Mango growth
K^+	3.33-4.0%	0.1-0.15mg/g
Ca^{+2}	0.6-0.9%	0.6-1.0mg/g
Mg^{+2}	0.28-0.36%	0.09 -0.15 mg/g
Na^+	0.0025-0.005%	-
F^-	-	-
pH	-	6.5 - 7.0
EC	-	< 1 dSm-1

Table 3 shows the optimum constituents levels prescribed for Banana and Mango cultivation (Daniells & Armour, 2008). Soil from reference locations showed slightly higher K^+, Mg^{2+}, Ca^{2+}, Na^+ concentrations than the desirable values given in Table 3. However, at the reject water disposing points, K^+, Mg^{2+}, Ca^{2+}, Na^+ concentrations in soil were greater than the desirable values given in Table 3. Hence, the results indicated a drastic increase in the ion concentrations at the disposal sites compared to the desirable levels for the growth of selected plants which could be attributed to the direct discharge of RO reject water containing higher ions concentrations directly to the ground.

5 CONCLUSION

Soil and water samples were collected from sites in which direct disposal of RO reject water is practiced and analysed for various constituents to investigate the potential soil contamination. RO reject water comprised high concentrations of Ca^{2+}, Mg^{2+}, Na^+, K^+ and F^- ions. Soil samples from RO reject water disposal sites showed high concentrations of Ca^{2+}, Mg^{2+}, Na^+, K^+ compared to the levels of respective ions present in soil samples obtained from the reference sites. This effect was mainly attributed to the accumulation of such ions in the soil due to direct discharge of RO reject water with excessive amounts of Ca^{2+}, Mg^{2+}, Na^+, K^+ onto the ground. The concentration of Ca^{2+}, Mg^{2+}, Na^+, K^+ in the soil from RO reject water disposal sites also exceeded the optimum constituents levels specified for Banana and Mango cultivation. These optimum levels are considered only for comparison purpose and it does not imply that all the ions would be taken up by these trees. In conclusion, soil contamination was observed due to direct discharge of RO reject water onto the ground, which may lead to reduction of soil fertility and retarded plants growth in the long run.

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