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RESEARCH ARTICLE

Quality of surface and ground waters for domestic and irrigation purposes in CKD/CKDu prevalent areas in Moneragala District, Sri Lanka

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Abstract: Total of 152 water samples from CKD/CKDu endemic areas and 30 water samples from non-CKDu prevalent areas in the Moneragala District were collected separately. pH values of water samples varied from 5.04 to 8.37 which are within the permissible limit prescribed by World Health Organization. More than 15% of water samples showed low Dissolved Oxygen (DO) values indicating heavy contamination by organic matter. Electrical conductivity was high ranging between 32 and 2865 µS/cm indicating higher mineralization in groundwater. The major ion chemistry reveals that the array of abundance of cations was variable as $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ in dug wells, $Ca^{2+} > Na^+ > Mg^{2+} > K^{2+}$ in tube wells and $Ca^{2+} > Na^+ > K^+ > Mg^{2+}$ in surface waters, while anions varied as $HCO_3^- > Cl^- > SO_4^{2-} > F^-$ in water samples in both seasons. Computed WQI, 43%, 33%, and 82% for dug wells, tube wells and surface water respectively were in good water quality in this area, while waters in 30% and 25% of dug and tube wells respectively exceeded the value of 100 showing not suitable category. Considering irrigation quality, 88%, 93% and 96% of dug, tube and surface waters respectively were less than the permissible level. SAR values in the study area ranged from 0.08 to 4.91 meq/L by showing no danger of sodium as per SAR. The bulk of studied waters are appropriate for irrigation according to Residual Sodium Carbonate (RSC). Considering KR and PI, majority of water samples of the study area are suitable for irrigation purposes.

Keywords: groundwater, surface water, water quality index, irrigation water, CKDu

INTRODUCTION

In the world community, spreading of chronic diseases has shown a large occurrence. Although Hypertension and Diabetes are known to be the main causes for high prevalence of Chronic Kidney Diseases (CKD), the majority of patients do not show any identifiable causes and it has been named CKD of unknown etiology (CKDu)(Dharma-Wardana *et al.*, 2015). CKDu has been a concern in many countries since the mid-twentieth century including Canada (Arora *et al.*, 2013), United States (Coresh *et al.*, 2007), China (Lin *et al.*, 2014), South-Asia (Jessani *et al.*, 2014) etc. The CKDu found in Sri Lanka is somewhat similar to Balkan Endemic Nephropathy (BEN) recorded in Serbia, Bosnia, Croatia, Bulgaria and Rumania (Batuman, 2006; Stefanović, 1999). It is a slowly progressive chronic tubular-interstitial disease that is present among farmers affecting with a possible environmental nephrotoxin (Batuman, 2006).

Based on observations of past researches, there is a strong evidence that CKDu has a profound relationship with multi-factorial causes such as cyanobacterial toxins (Madhushankha *et al.*, 2016), ocharatoxins (Wanigasuriya *et al.*, 2008), aristalochic acid (Weaver *et al.*, 2015), poor-quality aluminum utensils for cooking purposes and high fluoride drinking water ((Ileperuma *et al.*, 2009), long term exposure to sunlight and dehydration (Siriwardhana *et al.*, 2015) and water ionicity (Dharma-Wardana *et al.*, 2015). Also, it was pointed out that CKDu is attributed to presence of irrigation works and rivers that bring-in fertilizer runoff from intensely agricultural regions (Wimalawansa, 2016). Several studies have shown the potential of correlation of heavy metals such as mercury, chromium, uranium, lead and cadmium (Doul *et al.*, 1980) arsenic, gold, iron, antimony, platinum and thallium (Maher, 1976) and silicon (Saldanha *et al.*, 1975) with CKDu.

Since the reported incidences of CKDu have increased from several provinces in dry zone in Sri Lanka (Ramachandran, 1994), it has become a major health issue in North Central, Uva, North Western, Central and Northern provinces in Sri Lanka (Gunatilake *et al.*, 2015; Wanigasuriya, 2012). Hence, identifying the causes of CKDu in order to prevent and treat the disease as well as save vulnerable lives is urgently needed.

Since recently, out of the sources of contamination, agriculture has shown both direct and indirect effects on water quality. The deterioration of the quality of drinking water threatens human health, economic development, and social prosperity (Milovanovic, 2007). The people who are living in CKD/CKDu prevalence areas in the country mainly use groundwater and surface water for

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domestic and agricultural purposes. Therefore, quality of surface water and groundwater has received immense attention since water with good quality is required for domestic and irrigation needs. Water supply and drainage board in Moneragala District supplies surface water (reservoir water) and groundwater for domestic purposes after purification in some areas, while using it directly for irrigation practices. Various technologies such as Reverse Osmosis (RO) water, rain water harvesting, etc. are being used in endemic areas for domestic purposes. But feasibility studies need to be conducted to identify low cost technologies for continuing the sustainability. Hence, this study is aimed at understanding the quality of surface and groundwater by developing of a water quality index (WQI) to assess their suitability for domestic purposes. Suitability of water for irrigation purposes was monitored by considering several other irrigation water quality indices in CKD/CKDu prevalence areas in Moneragala District in Uva province, Sri Lanka.

Water Quality Index (WQI)

WQI is an important parameter for demarcating water quality and its suitability for drinking purposes ((Mishra *et al.*, 1985). There are many Water Quality Indices around the world (National Sanitation Foundation Water Quality Index), NSFWQI (Brown *et al.*, 1970), Florida Stream Water Quality Index, FWQI (Environment, 1995), British Columbia Water Quality Index, BCWQI (Zandbergen and Hall, 1998), Oregon Water Quality Index, OWQI (Cude, 2001) and the Canadian Water Quality Index (Khan *et al.*, 2004). For this study, Weighted Arithmetic Water Quality Index method was applied.

Weighted arithmetic water quality index method (WAWQI)

Weighted arithmetic water quality index method was proposed by Horton (1965) and modified by Cude (2001). This method has been widely used by various scientists (Balan *et al.*, 2012; Chauhan and Singh, 2010; Chowdhury *et al.*, 2012) and the calculations were made using the following equations (Brown *et al.*, 1972).

$$WQI = \sum_{i=1}^{n} w_i q_i / \sum_{i=1}^{n} w_i \quad (1)$$

Where w_i is the unit weight water quality for the i^{th} parameter and q_i is the quality rating scale of the i^{th} parameter.

$$w_i = \frac{k}{v_s} \quad (2)$$

$$k = \frac{1}{\sum_{i-1}^{n} v_i} \quad (3)$$

$$q_i = \frac{(v_i - v_o)}{(v_s - v_o)} \quad (4)$$

Where k is the proportionality constant, v_i is the estimated concentration of the i^{th} parameter in the laboratory analysis, v_o is the real value of the i^{th} parameter in pure water (v_o = 7 for pH and 0 for other parameters (Chowdhury *et al.*, 2012), v_s is the standard value according to the Sri Lanka Standards (SLS 614:2013). Rating of the water quality according to the WQI is given in the Table 1. This index has already been developed for Jaffna peninsula of Sri Lanka (Harshan *et al.*, 2017). As a further attempt, this study illustrates the developing of the WQI for surface water and groundwater in CKDu prevalence area in Moneragala District in Sri Lanka.

Irrigation water quality

Sodium Absorption Ration (SAR), Percent Sodium (%Na), Residual Sodium Carbonate (RSC), Magnesium Hazard (MH), Kelley's Ratio (KR) and Permeability Index (PI) were calculated using the following Equations 5, 6 (Richards 1969), Equation 7 (Todd 1980), Equation 8 (Kelly, 1963) and Equation 9 (Doneen, 1962) to monitor the irrigation water quality.

$$SAR = [Na^+] / \sqrt{\{[Ca^{2+}] + [Mg^{2+}]\}/2} \quad (5)$$

$$\%Na = \frac{\{[Na^+] + [K^+]\} \times 100}{\{[Ca^{2+}] + [Mg^{2+}] + [Na^+] + [K^+]\}} \quad (6)$$

$$Magnesium\ Hazard\ (MH) = \frac{[Mg^{2+}]X100}{[Ca^{2+}] + [Mg^{2+}]} \quad (7)$$

$$Kelley's\ Ratio = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (8)$$

$$Permeability\ Index = \frac{(Na^+ + \sqrt{HCO_3^-}) * 100}{(Ca^{2+} + Mg^{2+} + Na^+)} \quad (9)$$

where all cationic concentrations are expressed in meq/L.

Study Area

Moneragala District in Uva Province lies between the northern latitudes 6.17" and 7.2.8" and eastern longitudes 80.50" and 81.35". This district is divided into 9 Assistant Government Agent divisions, namely

Table 1: Water quality rating as per the weight arithmetic water quality index method.

WQI value	Rating of water quality
0-25	Excellent water quality
26-50	Good water quality
51-75	Poor water quality
76-100	Very poor water quality
>100	Unsuitable for drinking purposes

Bibile, Medagama, Madulla, Badalkubura, Moneragala, Siyabalanduwa, Buttala, Tanamalwila and Wellawaya. Topographically Moneragala district is in a transitional zone from central highlands to flat lowlands. According to the landscape, three terrain types could be identified as highly mountainous terrain, hilly, steep and rolling terrain and undulating and flat terrain with elevation between 550 to 1400 m, 160 to 550 m and below 150 m respectively (Cooray, 1967). There are seven river basins which drain crossing Moneragala district. These rivers originate in the west central high lands, flow towards east, south-east and south. Several drainage basins (Hedaoya, Walawe, Kirindi oya, Kiribban oya, Wila oya, Manik ganga, Malala oya) cover approximately 80% of the land area of the district. Fluctuation levels and volumes of these river basins depend on the seasonal rains.

Quantity of rain received over the nothern and eastern parts of the country during the north-east monsoon is less than the amount received over south-west during the south-west monsoon. The dry zone environment of Moneragala is basically determined by the seasonal spell of rains, resulting in two seasons namely Maha and Yala (Rubasinghe et al., 2015). Total rainfall of the district ranges between 1328-1821 mm in a year. Over 84% of rain is received during the seven rainy months from October to January and from March to May. Corresponding to these long and short rainy seasons, there are long and short dry seasons (June-September and February respectively). The low rainfall during these periods and reduction of rainfall in the upper catchment areas result in frequent drought conditions in a major part of the irrigated area in Moneragala District.

METHODOLOGY

Regional Directors Health Services Office (RDHSO) in Moneragala district has identified more than 677 CKD/CKDu cases by 2017. Out of them, purposive households were visited and water samples were collected directly from their drinking water sources covering two seasons in 2017. Water samples were collected from dug wells, tube wells and surface water bodies (rivers, reservoirs etc). All samples were properly numbered and a survey was conducted while sampling to get all information about cultivation as well as the patients details (age, occupation, income, clinical states including smoking, diabetes, hypertension etc.).

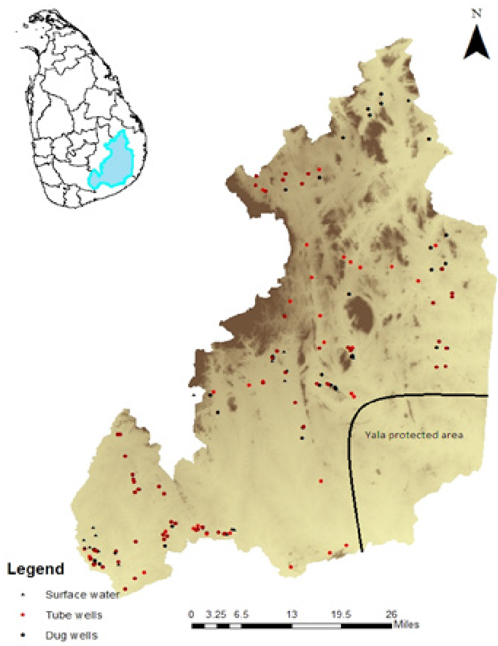
A total of 182 water samples (101 dug wells, 60 tube wells and 21surface water from reservoirs and rivers) were collected covering both seasons from the district (Figure 1). A total of 103 samples (67 dug wells, 19 tube wells, 17

Table 2: Standard methods used in chemical analysis.

Water quality parameter	Standard analytical method
Alkalinity	H_2SO_4 titrimetric method
Total hardness (TH), Cl^-	titrimetric methods
SO_4^{2-}, F^-, NO_3^-, PO_4^{3-}	HACH DR 2700 spectrophotometer
Na^+, K^+, Ca^{2+}, Mg^{2+}	Inductive Couple Plasma – Mass Spectroscopy (ICP-MS).

The HCO_3^- and CO_3^{2-} were calculated using alkalinity and pH values.

Figure 1: Location map of the study area.



surface water samples) were selected from drinking water sources of CKD/CKDu patients and 49 nonpatients' well water samples (23 dug wells, 22 tube wells and 4 surface samples) were collected from CKD/CKDu endemic areas in the district. Other 30 water samples (11 dug wells and 19 tube wells) were collected from non-prevalent areas in the district. Water samples were collected into high-density polyethylene bottles which were acid soaked overnight and then washed thoroughly with distilled water. Two subsets of samples were also collected for laboratory analysis. One set of samples was filtered and acidified by adding several drops of ultra-pure nitric acid for cation analysis, while the un-acidified sample set was used for anion analyses (Table 2). pH, EC, temperature, oxidation-reduction potential (ORP) were measured *in situ* using pre-calibrated Hach Sension pH/EC Multiparameter. All collected samples were kept cooled at 4º C until the analyses were performed.

RESULTS AND DISCUSSION

According to the data collected from RDHSO, a total of 677 CKD/CKDu patients have been identified in 2017 from different areas in Monaragala district (Figure 2). According to the Figure 2, the highest number of CKD/CKDu patients (167) was recorded from both Thanamalwila and Sewanagala DS divisions, while 114 patients recorded from Siyabalanduwa DS division. Comparatively other DS divisions of Thanamalwila, Sewanagala and Siyabalanduwa areas show the highest prevalence of CKD/CKDu patients in Monaragala district. At a glance, northern part of the Monaragala District shows lesser number of CKD/CKDu patients, whereas more patients are reported in southern and southwestern parts of Monaragala District.

Based on the recorded data, total of 116 patients were interviewed during the site visits. High blood pressure and diabetics were identified as main causes for CKD. The patients who are not attributed to diabetes, hypertension or other known aetiologies were categorized as CKDu. Survey results revealed that 31.9% of CKD patients belonged to CKDu group (Figure 3 a). Among those CKDu patients, highest number of patients was recorded from Thanamalwila and Sewanagala areas respectively (Figure 3b).

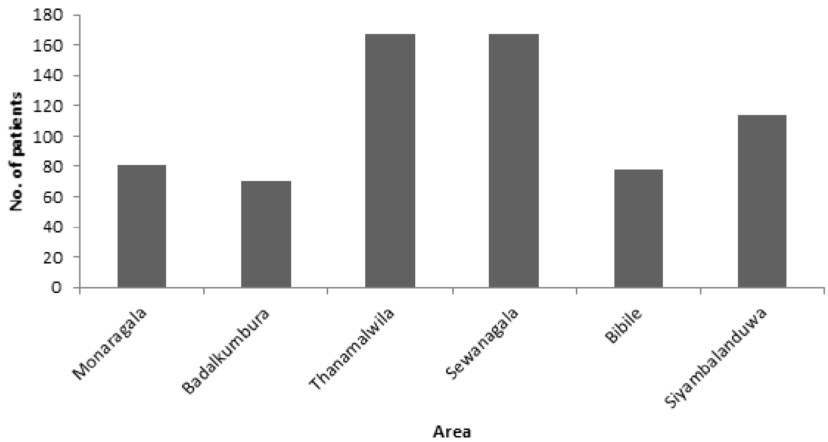
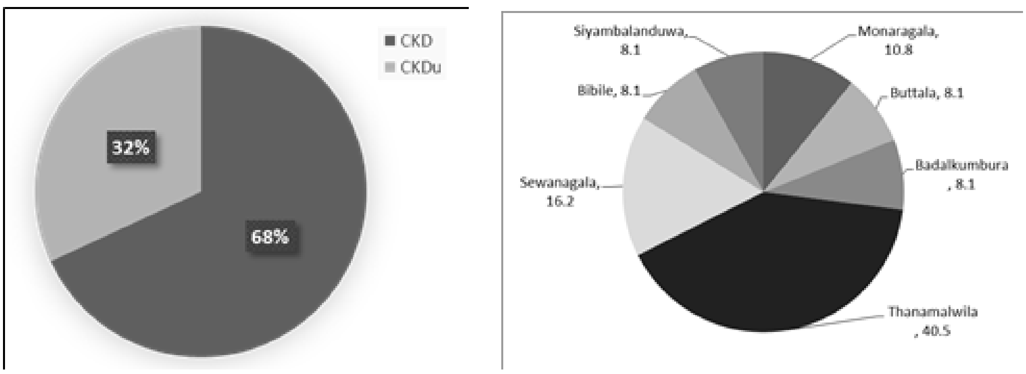


Figure 2: Number of CKD/CKDu patients identified by 2016.



a b

Figure 3: Recorded CKD and CKDu patients (a) and prevalence of CKDu patients in each DS division (b) during the study.

Groundwater quality for drinking purposes

The compositions of surface and groundwater in the study area are summarized in Table 3. The availability of drinking water is an essential requirement of humans as stipulated by international law and the declarations (Kausar *et al.* 2011). In drinking water, pH is one of the most significant quality parameters which may affect health of humans (Rahmanian *et al.* 2015).

pH values below 4 produce a sour taste and higher values above 8.5 give an alkaline taste (Trivedy *et al.,* 1986). In the present study, the pH values of water samples varied from 5.04-8.37 in dug wells, 5.61-8.16 in tube wells and 5.77-8.01 in surface water showing that all samples are within the limit prescribed by WHO, 2003. Dissolved oxygen (DO) reflects the physical and biological processes prevailing in water and indicates the degree of pollution in water bodies. In this region, more than 15% of water samples (groundwater and surface water) showed low DO values (DO less than 5.00) indicating heavy contamination by organic matter. Electrical conductivity (Reddad *et al., 2002*)is found to be very high ranging between 32 and 2865 µS/cm in dug wells and 69-1823 µS/cm in tube wells when compared to that of surface water (average value -321 µS/cm). This indicate higher mineralization of groundwater (Rubasinghe *et al.*, 2015). Only 11% of dug wells and 19% of tube wells water exceeded the permissible level of EC, i.e.,1500 µS/cm (WHO and Organization, 2003).

Considering the Figure 4, it can be clearly observed that most of the samples exceed the desirable limit of 300 mg/L (WHO and Organization, 2003) for total hardness. Higher SO_4^{2-} ions in groundwater samples (average 37 mg/L in dug wells and 36.7 mg/L in tube wells) indicate the occurrence of permanent hardness in aquifers of this region.

Almost 50% of dug well water, 42% of tube well water and all surface water bodies in the area showed less than permissible level of TDS according to the WHO guidelines

Figure 4: The relationship between EC and Total Hardness.

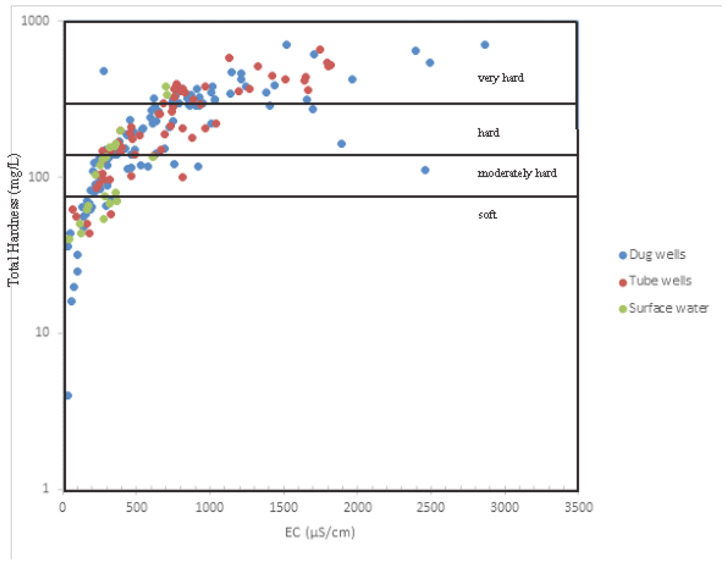


Table 3: The compositions of physico-chemical parameters in groundwater and surface water.

Water sources	pH	DO (ppm)	TDS (ppm)	EC (µS)	NO_3^- (ppm)	PO_4^{3-} (ppm)	SO_4^{2-} (ppm)	F^- (ppm)	Cl^- (ppm)	HCO_3^- (ppm)	Hardn. (ppm)	Na	Mg	K	Ca
Dug wells															
Min	5.04	1.88	28.27	32.16	1.33	0.02	2.00	0.02	11.00	12.0	4.000	4.07	0.57	0.29	1.46
Max	8.37	21.4	4523	2865	11.5	4.86	540	2.93	1100	738	1464	425	56.6	7.28	128
Ave	7.07	8.34	650.8	704.9	2.70	0.46	37.1	1.00	65.61	262	232.4	46.1	10.9	1.39	42.1
Tube wells															
Min	5.61	1.62	61.23	69.68	1.33	0.04	2.00	0.10	13.0	42	44	4.70	2.526	0.55	11.10
Max	8.16	28.4	1610	1823	7.97	1.24	190	5.65	301	518	660	164.5	52.28	7.41	206.2
Ave	7.15	7.49	669.4	765.3	2.53	0.27	35.7	1.11	61.1	270	253	51.64	16.02	2.06	58.40
Surface Water															
Min	5.77	3.24	38.50	42.91	0.3	0.03	2.0	0.05	8.00	20.0	40.0	5.541	0.28	0.460	10.24
Max	8.01	23.4	636.8	710.3	3.6	0.82	28	1.06	41.0	330	382	39.30	2.90	56.57	64.88
Ave	7.27	9.39	244.0	320.6	0.8	0.25	8.0	0.36	19.5	119	125	15.23	2.26	13.84	27.18

(WHO and Organization, 2003). High TDS water may be due to the high evaporation process, low rainfall and high ambient temperature in the region. Total alkalinity of 52% in dug wells, 62% intube wells and 9.5% in surface water bodies exceed the permissible level of 200 ppm due to , and OH^- compounds; and $^-$ in top soil layer (Garg *et al.,* 2008).

These results show that fluoride levels in water consumed by CKD/CKDu patients in affected areas vary from 0.02 to 2.93 mg/L in dug wells, 0.10-5.65 mg/L in tube wells and 0.05-1.06 mg/L in surface water bodies. Out of the studies samples, 60% of the dug well samples, 73% of tube well samples and 19% of surface water samples are above the limit (0.5 mg/L) recommended for tropical countries by the WHO (Chandrajith *et al.*, 2011). Therefore, it is apparent that people in CKD/CKDu affected areas in the district are already being contaminated with high amounts of fluoride (Dharmagunwardane and Dissanayake, 1993).

The Cl^- content was found to vary between 11 and 1100 mg/L in dug wells, 13-301 mg/L in tube wells and 8.0-40 mg/L in surface water in CKD/CKDu areas. Chloride in all samples collected from non-prevalent areas showed less than the permissible level (250 mg/L) prescribed by WHO, 2003. The major ion chemistry reveals that the array of abundance of cations was serried as $Na^+ .> Ca^{2+} .> Mg^{2+} > K^+$ in dug wells, $Ca^{2+} > Na^+ > Mg^{2+} > K^+$ in tube wells and $Ca^{2+} > Na^+ > K^+ > Mg^{2+}$ in surface waters. The abundance order of anions varied as $HCO_3^- > Cl^- > SO_4^{2-} > F^-$ in all groundwater samples and surface water samples in both seasons.

Calculation of WQI

For the calculation of WQI, twelve important parameters are considered (pH, Total Alkalinity, Total Hardness, Chloride, Sulfate, Nitrate, Phosphate, Fluoride, Calcium, Sodium, Potassium, and Magnesium). The WQI calculates by using water quality standards. In this study, the computed WQI values range from 0.54 to 338.04 Considering WQI, overall in almost 43% of the dug wells, water samples are of good water quality in this area and 30% of the samples exceeded the WQI value of 100 showing the water is not suitable for drinking purposes. The high value of WQI can be attributed mainly to the higher values of fluoride. WQI of tube wells water show that 33.33% of samples are good quality for drinking and domestic purposes while 42% of water samples falls into poor drinking water quality category. Only 25% of water sample exceeds WQI of 100. Eighty two percent of the surface water samples fall in good water category and the rest of the samples are in poor water category. None of the surface water samples exceeded the maximum value of WQI 100.

Suitability of water for irrigation purposes

The groundwater, river and tank water of the study area are used for irrigation purposes. Water used for irrigation always contains measurable quantities of dissolved substances (salts). Salts usually contain small amounts of dissolved solids originating from dissolution or weathering of the rocks. The main soluble constituents are Ca^{2+}, Mg^{2+}, Na^+ as cations and Cl^-, SO_4^{2-} and HCO_3^- as anions. The various salts present in the irrigation water affect plant growth, soil structure and permeability (Mohan *et al.* 2000).

Crops are very sensitive to pH of the irrigating water. The best range of pH for irrigation is between 6.5 and 8.4 (Bauder *et al.,* 2010) indicating all studied samples are suitable for irrigation purpose (Table 4). The total concentration of soluble salts in irrigation water can be classified into low (C1), medium (C2), high (C3) and very high (C4) salinity zones and the values are shown in the Table 3. Higher EC in water creates a saline soil.

The amount of sodium in irrigation water is referred to as Na%. The Na content of water reacts with the soil and accumulates in the pore spaces thus reducing its permeability (Khan and Abbasi, 2013). Deterioration of soil structure, poor infiltration, and low aeration are caused due to high Na% (>60 %) in agriculture water supply.

Table 4: Suitability of water for irrigation purposes according to salinity.

TDS(ppm)	EC(uS/cm)	Salinity class	Necessary management for use in irrigation	Representing percentage, %
<150	<250	Excellent (C1)		Dw-22
				Tw-12
				Sw-29
150-500	250-750	Good (C2)		Dw-39
				Tw-42
				Sw-71
500-1500	750-2250	Permissible (C3)		Dw-35
				Tw-47
				Sw-nil
1500-3000	2250-5000	Unsuitable (C4)		Dw-4
				Tw-nil
				Sw-nil

According to Na%, 88% of dug wells, 93% of tube wells and 96% of surface water are less than the permissible level of 60 (Table 5).

Plot of Electrical conductivity verses Na% is important to evaluate the suitability of water for irrigation purpose (Khan and Abbasi, 2013; Khodapanah *et al.,* 2009). The binary plot consists of five distinct agriculture water quality fields (Figure 5). Adopting this scheme, studied samples are found in permissible to excellent range while few are unsuitable for irrigation purposes.

The SAR is an important parameter for the determination of the suitability of irrigation water because it is responsible for the sodium hazard (Todd, 1980). High concentration of cations is mainly responsible for sodium or alkali hazard in irrigation water (Ogunfowokan *et al.,* 2013; Gholami and Srikantaswamy, 2009). Low SAR values are always desirable (Raihan and Alam, 2008) because it influences in filtration rate of water. The water of the study area was classified with respect to SAR values (Table 6). According to the above classification, the SAR values in the study area range from 0.08 to 4.91 meq/L and the samples of the study area cause no danger of sodium consideration in soil according to the SAR values.

Hazard of and on the quality of agricultural water is determined as Residual sodium carbonate (RSC) (Khan and

Table 5: Suitability of water for irrigation purposes according to Na%.

Na%	Suitability for irrigation	Dug wells, %	Tube wells, %	Surface water, %
<20	Excellent	22	16	29
20-40	Good	44	45	62
40-60	Permissible	22	32	5
60-80	Doubtful	11	7	4
>80	Unsuitable	2	Nil	Nil

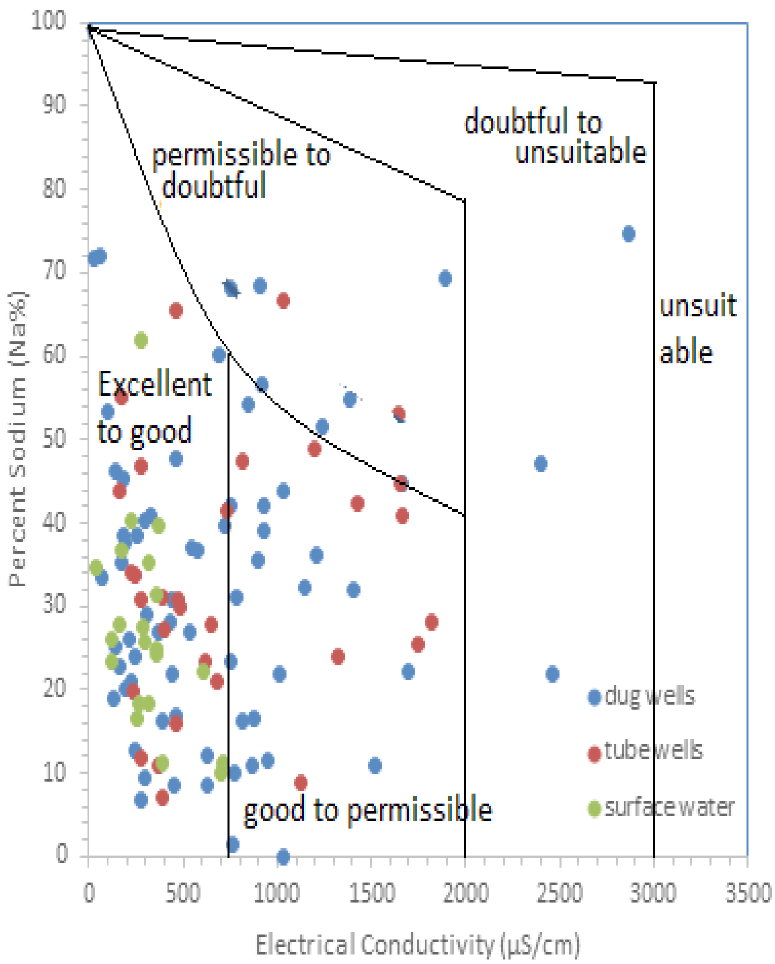


Figure 5: The salinity zones according to EC vs Na%.

Table 6: Suitability of water for irrigation purposes according to SAR.

SAR%	Suitability for irrigation	Dug wells, %	Tube wells, %	Surface water, %
<10	Excellent	100	100	100
10-18	Good			
18-26	Doubtful			
>26	Unsuitable			

Table 7: Suitability of water for irrigation purposes according to RSC (Camberato, 2001).

RSC	Suitability for irrigation	Dug wells, %	Tube wells, %	Surface water, %
<1.25	Safe	49	52	100
1.25<RSC<2.5	Moderate	23	19	
>2.5	Unsuitable	28	29	

Abbasi, 2013). According to Aghazadeh and Mogaddam (2010), high RSC restricts the movement of water and air in soil. According to RSC values, irrigation water is classified into three classes: safe, moderate, and unsuitable (Camberato, 2001) . Data in Table 7 show that bulk of the studied waters are appropriate for irrigation (RSC < 2.5 meq/L). Only 28% of dug wells and 29% of tube wells waters are considered unsuitable and harmful for irrigation.

The MH is also one of the important factors to evaluate quality of irrigation water. Gupta and Gupta (1987) mentioned that high MH affects the soil unfavorably, a harmful effect on soils appears when MH exceeds 50 the permissible limit of irrigation quality standards. In the present study, 28%, 18% and 20% of dug wells, tube wells and surface water sources respectively exceed the value 50 which may cause harm to soil. Therefore, it can be concluded that groundwater in most of the study area is found to be suitable for irrigation.

Kelly (1963) described the ratio of Na/(Ca + Mg) which evaluates the suitability of water for irrigation purposes. Kelley's ratio (KR) should not exceed 1 for irrigation water (Kelly, 1963). Among dug and tube wells, 75% and 85% samples have KR values <1 respectively, while 95% of surface water samples (KR<1) are suitable for irrigational uses. Rest of water samples has KR values ≥1.

The PI is employed to assess quality of irrigation water. Soil permeability is reduced by the consecutive use of water-containing high salts (Singh and Singh, 2008). According to the classification of PI, irrigation water with high permeability (>75%) is classified as Class I, while Class II has permeability between 75% and 50% (Nagaraju *et al*., 2006). Class I and Class II waters are categorized as good for irrigation purposes. The third category (Class III) is unsuitable with 25% of maximum permeability (Dhirendra *et al*., 2009). On the basis of the PI classification, majority of water samples of the study area belong to classes I and II (91% dug and tube wells in Class I and 9% in Class II) and suitable for irrigation purposes.

CONCLUSIONS

Geochemical studies of groundwater and surface water in CKD/CKDu endemic areas in Moneragala District display a trend of ionic abundances of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ in dug wells, $Ca^{2+} > Na^+ > Mg^{2+} > K^+$ in tube wells and $Ca^{2+} > Na^+ > K^+ > Mg^{2+}$ in surface waters and $HCO_3^- > Cl^- > SO_4^{2-} > F^-$ abundance trend of anions for both cultivation seasons (Yala and Maha). High range of EC (10%), TDS (42%), TH (47%) and (18%) may be due to high evaporation, mineralization and low rainfall. 76.5% of fluoride concentration of the groundwater samples exceeds the WHO permissible limit for tropical countries indicating direct impact of underground geology of the area to groundwater. Computed WQI varied between 0.53-338. Almost 39 and 33% of groundwater samples are in good and poor water category respectively while 28% groundwater samples are not suitable for domestic purposes according to WQI. The WQI values are very high in CKDu prevalence area showing the drinking water quality has direct impact with CKDu. It identifies that fluoride is the main parameter for changing WQI in the study area, with comparing other parameters. Also this study revealed that the communities who depend on dug wells which are in close proximity to the developed irrigation systems used for agriculture with seepage to the wells are more affected by CKDu compared to the other communities in the region. Therefore, treatments are essential before the consumption of groundwater for drinking purposes especially in CKDu prevalence area in Monaragala District. However, this study showed that reservoirs, small tanks and river waters are more suitable for domestic purposes. More than 88% of ground and surface water samples are less than the permissible level prescribed for Na. EC, SAR, Na%, RSC, MH, KR, and PI values show that a majority of the water samples from ground and surface water are fit for irrigation purpose except for a few samples. Poor water quality water due to high fluoride is mainly found in CKDu patients' wells in CKD/CKDu endemic areas. Also this study reveals that WQI can provide an excellent way as an easy interpretation indicator to detect changes in water quality.

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DECLARATION OF CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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