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ASSESSMENT OF GROUNDWATER QUALITY USING MULTIVARIATE STATISTICAL ANALYSIS IN THE MEDAWACHCHIYA AREA AND THE HURULUWEWWA AREAS IN ANURADHAPURA DISTRICT

Indunil Senanayke
Department of Zoology, University of Sri Jayewardenepura, Nugegoda, Sri Lanka,

Swarna Piyasiri
General Sir John Kotelawala Defence University, Kandawala Estate, Ratmalana, Sri Lanka

Rohana Chandrajith
Department of Geology, University of Peradeniya, Peradeniya, Sri Lanka,

Wasantha Nandalal
Department of Civil Engineering, University of Peradeniya, Peradeniya, Sri Lanka.,

Kamal Ranatunga
Department of Zoology, University of Sri Jayewardenepura, Nugegoda, Sri Lanka,

ABSTRACT

Water is a scarce commodity in North Central Province (NCP) of Sri Lanka and people use groundwater for consumptive purposes. 85% of the rural population in the NCP obtains water from shallow and deep wells. However, human health is affected by water quality in various ways. Therefore, the present study was focused to identify the quality of groundwater in Madawachchiya and Huruluwewa by using multivariate statistical analysis. Medawachchiya area and the Huruluwewa area were both separately divided into 30 quadrants and the middle point of each was taken as a sampling location. Altogether there were 60 water sampling locations. During the survey period of two years, twenty-four water quality parameters (Temperature, DO, pH, Electrical Conductivity (EC), Total Alkalinity (TA), Total Hardness (TH), Chloride (Cl), Nitrate, Phosphate, Fluoride, sulfate, Fe, Zn, K, Na, Mg, Ca, Cr, Cd, Se, Al, Pb, Mo, and As) were analyzed. Data analysis was performed by using the multivariate statistical analysis techniques as a tool. Five parameters including pH (p-0.787), fluoride (p-0.497), Fe (p-0.116), Mg (p-0.06) and as (p-0.532) were not significantly different, while all other parameters were significantly different in both areas. Three clusters in Medawachchiya and five clusters in Huruluwewa were identified. However, Medawachchiya area (13%) indicated very less amount of groundwater samples which were good for consumptive purposes than Huruluwewa (37%). Strong positive correlations were appeared in between TH vs EC (p-0.744), Orthophosphate vs K (p- 0.770) in Medawachchiya study area and TH vs EC (p-0.830), Cl vs EC (p-0.807), EC vs Na (p-0.778), EC vs Mg (p-0.788), Cl vs TH (p-0.719), TH vs Ca (p-0.715), and TH vs Mg (p-0.811) in the Huruluwewa study area. The water quality of both areas were moderated by the hydro-geochemical and agrochemical influencing factors. Study revealed that, majority of the groundwater wells were unsuitable for drinking purpose without any pre-treatment.

KEYWORDS: *Groundwater, water quality, Cluster analysis, Correlation, Factor analysis*

Corresponding author: SAMAIK Senanayake, Email: *indunil@sci.sjp.ac.lk*

1. INTRODUCTION

Water quality effects human health, economic development, and social prosperity. The quality of the groundwater depends on the atmospheric precipitation, inland surface water, quality of recharged water, and sub-surface geochemical processes (Vasanthavigar *et al*., 2010). Most of the water resources get contaminated due to natural activities such as precipitation, weathering activities, soil erosion, and anthropogenic activities such as industrialization, agricultural activities, and waste disposal. Water is a scarce commodity in North Central Province (NCP) of Sri Lanka and people use groundwater for consumptive purposes. 85% of the rural population in the NCP obtains water from shallow and deep wells for consumption (Lasantha *et al*, 2008, Jayewardene *et al*., 2010; Chandrajith *et al*., 2011a ;). According to the Censes 2011, 75% of the rural people in Anuradhapura district relied on the groundwater through dug well and tube wells. The shallow groundwater is recharged by seepage from small tank cascade systems (Panabokke, 2003; Kumari *et al*, 2016; Kumari, 2020). Due to lack of suitable drinking water, people living in NCP suffer from a different kind of water-borne diseases (Mahagamage & Manage, 2019; de Silva 2019)

In late nineties, medical specialists have identified an alarming high incidence of a new form of Chronic Kidney Disease (CKD) that was later named as Chronic Kidney Disease of unknown etiology (CKDu) as indicated by Wanigasuriya *et al*, 2007. It is a non-communicable disease (Elledge *et al*., 2014) in which CKDu usually emerges slowly and not appearing until that reaches stages of 3 or 4. The CKDu is more prevalent in the north-central region of Sri Lanka, believed to be associated with geo-environmental nephrotoxins in which causing slowly progressive chronic fibrosis of kidneys (Athuraliya, 2008). Most researches suggested that the etiology of this disease may be a combination of several environmental factors such as high level of fluoride in groundwater, heavy metals such as cadmium, exposure to inorganic pesticides, and use of aluminum utensils (Herath *et al*., 2005; Bandara *et al*., 2008; Wanigasuriya, 2007; Ileperuma *et al*., 2009; Wanigasuriya, 2011; Cooray *et al*., 2019).

The CKDu in the dry zone of Sri Lanka is somewhat similar to a cases reported in Balkan countries; Bulgaria, Romania, Serbia etc. in Southern Europe. A similar type of kidney diseases with unknown etiology was reported in countries of North Central America; El Salvador, Mexico and Nicaragua, Asian countries; India, China and Taiwan and African countries such as Congo, Egypt, Morocco, Senegal, Nigeria, Libya, Burkina Faso, Tunisia and Sudan, etc. (Tatu *et al*., 1998; Stefanovic, 1999; Batuman, 2006; Stefanovic and Polenakovic, 2009).

Water quality is a combined effect of several governing parameters. Analysis of individual parameters and interpretation of data for single parameters do not give the interpretation of the collective effect of parameters on water quality.

The early studies considered individual water quality parameters and correlate them with the CKDu distribution. Therefore, the present study was focused to examine the multifactorial effects of water quality to find out the suitability of water for drinking purposes and to identify the potential environmental factors and anthropogenic activities that could affect the variation of water quality in selected study sites.

2. METHODOLOGY

CKDu high prevalence Madawachchiya area and less prevalence Huruluwewa area were selected as study sites. Both areas were separately divided into 30 quadrants and the middle point groundwater well is selected as the sampling locations (Figure 1). Dug wells, Tube wells, and springs were selected as groundwater sources but not in equal numbers. Selected wells were used for drinking purposes in the relevant area. All together twenty-four water quality parameters were analyzed.

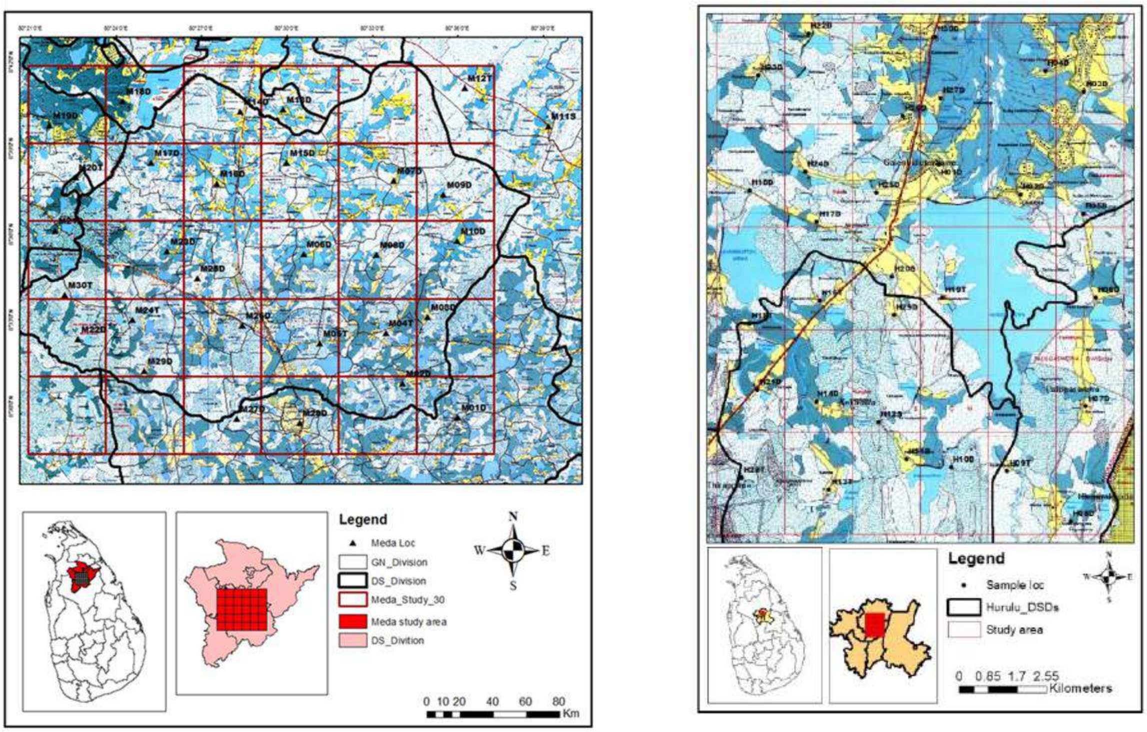

Figure 1: Madawachchiya (Left) and Huruluwewa (Right) study areas

Temperature, DO, pH, Electrical Conductivity (EC) Total alkalinity, and total hardness were measured in the field soon after the sampling. Samples were analyzed using digital meters (pH; SenslON^{TM}+pH1, DO; SenslON^{TM} +DO6, Electrical Conductivity; SenslON^{TM} +EC5), digital titrator: (model 16900, HACH) (alkalinity, hardness and chloride) and HACH 2700DM Spectrophotometer (nitrate, phosphate, fluoride, iron and sulfate). Zn, K, Na, Mg, Cr, Cd, Se, Al, Hg, Pb, Mo, and As, Cr, Cd, Se, Al, Pb, Mo and As were analyzed using Inductively Coupled Plasma Mass Spectrometry (ThermoICapQICP-MS) at the Bandaranayake Memorial Research Institute in Nawinna and Ca was measured by using Atomic Absorption Spectrophotometer (ThermoiCE 3000) at University of Sri Jayewardenepura.

Mean values of pH of wells in both study areas were corrected for temperature by using pH temperature correction calculator. The corrected values were taken for further analysis (https://www.hamzasreef.com/Contents/Calculators/PhTempCorrection.php).

The statistical analyses was conducted through the SSPS 16.0 version. Analysis of Variance (ANOVA) and t-test was conducted to find out whether the different sources are significantly different from each other. Cluster analysis was carried out to identify similar water quality locations by using 24 water quality parameters. The correlations of each parameter were measured by using the correlation coefficient (r). According to Kumari & Rani (2014) $r > 0$ indicate positive relationship and $r < 0$ which indicate a negative relationship in parameters while $r = 0$ indicates no relationship. The strength of the relationship can be determined by using this r which is when closer to +1 or -1 gives a greater relationship. This analysis used to distinguish the correlation between different parameters

3. RESULTS

Due to lack of suitable drinking water available for consumption, people living in NCP suffer from a different water-borne diseases. The results of this study indicates the status of water quality based on 24 water quality parameters analyzed in 60 wells in Madawachchiya and Huruluwewa.

Out of the 24 measured parameters in the two study areas, five parameters including pH (*p*-0.787), fluoride (*p*-0.497), Fe (*p*-0.116), Mg (*p*-0.06) and As (*p*-0.532) were not statistically significantly different. However, all other parameters were significantly different in two study areas (Table 1). In both study areas, mean values of EC, total alkalinity and total hardness were greater than the threshold standard limits specified by the World Health Organization & Sri Lanka Standards drinking water standards.

Mean values of calculated for water quality parameters were plotted against their sources to find out whether there is any significant difference in different water sources in the two study areas. Most water quality parameters were significantly different in dug wells, tube wells, and springs. Medawachchiya study area except Cr (*p*-0.199), As (p-0.381), Cd (*p*-0.237), Zn (*p*-0.637), and Se (*p*-0.354), all other water quality parameters were significantly different in the three water sources. In Huruluwewa except for As (*p*-0.900), Cd (*p*-0.315), Zn (*p*-0.968), and Se (*p*-0.140), all other parameters were significantly different in the three water sources (Table 2). Grey color indicates the parameters which are not significantly different.

3.1 Cluster Analysis

Cluster analysis was carried out on twenty-four water quality parameters to identify the homogenous wells in both study areas. All wells were categorized into five clusters. The cluster results were compared with water quality values in both study areas to identify the different water quality categories in each cluster. Medawachchiya shows three clusters and Huruluwewa shows five clusters as illustrated Cluster dendrogram (Figure 2). Based on the dendrogram, there are two major clusters in the rascal length of 25. Mmajor cluster A is divided into three sub-clusters and major cluster B is categorized into two sub-clusters. Characteristics are also considered when naming the clusters. The pollution level increase from cluster 01 to cluster 05. For the interpretation purpose C1 to C5 clusters were named as follows:

C1 - Low contaminated
C2 - Moderately contaminated
C3 - Marginally contaminated
C4 – Highly contaminated
C5 – Very highly contaminated

Table 1: Two Sample t-test to compare the significance of the parameters in the two study areas; Medawachchiya and Huruluwewa

No	Parameter	*P* value
1	Temperature	0.000
2	EC	0.000
3	DO	0.001
4	pH	0.787*
5	Total hardness	0.005
6	Total alkalinity	0.008
7	Sulfate	0.004
8	Nitrate	0.000
9	Ortho P	0.000
10	Fluoride	0.497*
11	Chloride	0.000
12	Fe	0.116*
13	Na	0.000
14	K	0.000
15	Ca	0.002
16	Mg	0.068*
17	As	0.532*
18	Cd	0.000
19	Zn	0.003
20	Se	0.000
21	Mo	0.000
22	Pb	0.002
23	Cr	0.000
24	Al	0.000

Table 2: Analysis of Variance in dug wells, tube wells and spring water qualities in both study areas

	Medawachchiya				Huruluwewa			
Parameter	Dug well	Tube well	Spring	*p*-value	Dug well	Tube well	Spring	*p*-value
Temp	28.5	29.9	28.4	0.000	28.2	29.3	27.9	0.000
EC	951	807	121	0.000	1108	1732	118	0.000
DO	5.26	5.12	5.28	0.005	5.35	4.7	5.13	0.000
pH	7.7	7.2	6.2	0.000	7.8	7.2	6.1	0.000
Total hardness	295	271	19	0.000	293	473	30	0.000
Total alkalinity	302	285	15	0.000	280	311	15	0.000
Chloride	67	50	24	0.000	97	238	10	0.000
Sulphate	24	14	1	0.000	18	23	0	0.000
Fluoride	0.73	0.64	0.03	0.000	0.72	0.69	0.03	0.000
Ortho P	0.32	0.29	0.14	0.013	0.23	0.25	0.08	0.000
Nitrate	1.9	1.0	0.4	0.001	0.9	0.8	1.5	0.000
Fe	0.03	0.04	0.02	0.001	0.03	0.05	0.03	0.001
Cr[µg/L]	0.81	0.97	0.7	0.199	0.94	2.1	0.93	0.000
As [µg/L]	0.27	0.3	0.14	0.381	0.26	0.25	0.27	0.900
Cd [µg/L]	0.34	0.39	0.26	0.237	0.27	0.28	0.32	0.315
K [mg/L]	3.3	1.2	1.0	0.039	1.1	2.9	1.5	0.000
Ca [mg/L]	33.5	26.5	1.1	0.000	37.2	44.1	1.6	0.000
Na [mg/L]	43.3	37.4	7.7	0.000	56.1	83.4	7.3	0.000
Mg [mg/L]	20.0	18.4	6.1	0.000	20.5	29.2	2.3	0.000
Zn (µg/L)	15.7	14.8	13.3	0.637	17.6	17.7	18.2	0.968
Se (µg/L)	3.7	3.4	2.4	0.354	4.5	5.3	3.9	0.140
Mo (µg/L)	1.07	0.56	0.64	0.018	1.54	1.58	0.69	0.025
pb (µg/L)	0.73	2.05	0.19	0.000	0.62	0.97	0.77	0.000
Al [µg/L]	37.9	53.5	35.6	0.001	63.8	51.6	81.7	0.004

The parameters which are not significantly different are indicated in ash colour

3.2 Correlation analysis

The correlation is used to measure the strength of statistical significance and the association between two variables. The summary of the correlation analysis is tabulated in table 3. Both study areas indicate a strong positive correlation between total hardness and EC. Strong and moderate positive correlation indicates in between, total alkalinity vs. EC, Chloride vs. EC, Sulfate vs. EC, Ca vs. EC, Na vs. EC, Mg vs. EC, total alkalinity vs. total hardness, Sulfate vs. total hardness, Mg vs. total hardness, Mg vs. total alkalinity, Na vs. Sulfate and Mg vs. Na parameters in both study areas.

All correlated parameters in both study areas (EC, total hardness, total alkalinity, Na, Ca, Mg, Cl, and Sulfate) originate from the dissolution and weathering of rock materials. Therefore, those factors were correlated. Ca vs total hardness, Na vs total hardness, sulfate vs total alkalinity, Cl vs total hardness, Na vs. total alkalinity, fluoride vs. total alkalinity, Na vs. chloride, Mg vs. chloride, Mg vs. sulfate, fluoride vs. sulfate and Mg vs. Ca were weakly correlated in Medawachchiya and strongly and moderately correlated in Huruluwewa study area.

Dissolution of minerals during the infiltration is different in Medawachchiya to Huruluwewa possibly due to differences in precipitation. According to the Meteorological data, the average precipitation for the study period was 116 mm/month in Medawachchiya and 140 mm/month in Huruluwewa. The average precipitation in Huruluwewa is higher than that of Medawachchiya. Therefore, the amount of dissolution is low in Medawachchiya than in Huruluwewa. It may be the reason for the weak correlation in the above parameters in Medawachchiya.

Medawachchiya has strongly and moderately correlated parameters such as total alkalinity vs. total hardness, orthophosphate vs K, sulfate vs. Cl, and K vs sulfate. However, in Huruluwewa, weak or no correlations exist between the above parameters. EC is a measurement of dissolved minerals in the water. Therefore, EC is closely related with the total hardness which represent the Ca and Mg ions in water which is derived from limestone, dolomite, or chalk aquifers. Most of the mineral ions (Ca, Mg, Na. K, P, Cl, and SO4) dissolve in groundwater.

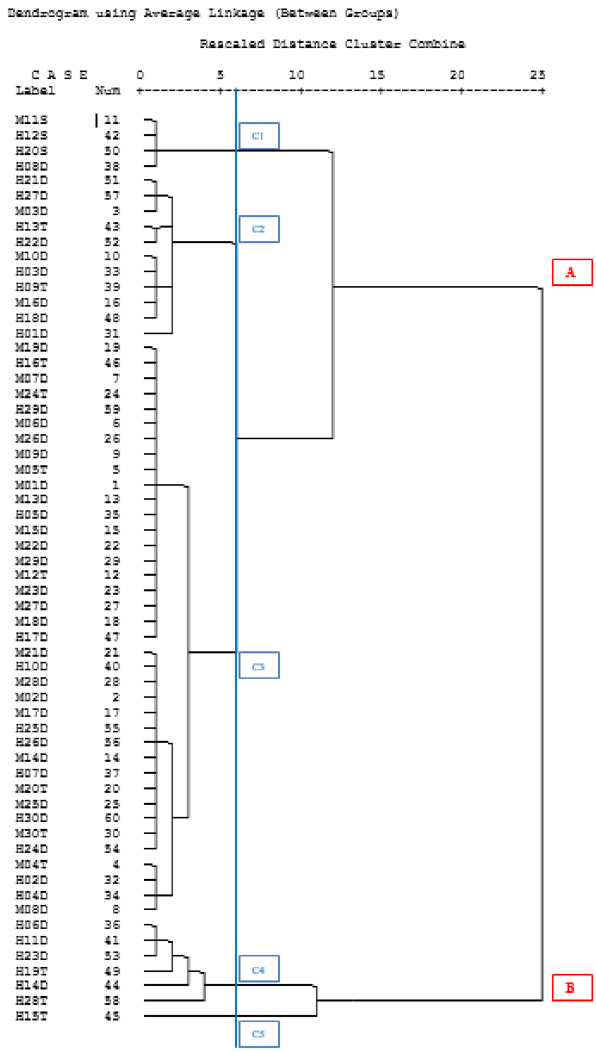

Figure 2: Dendrogram of the sampling using average linkage of Medawachchiya and Huruluwewa area sampled wells

Table 3: Summary of correlation in both study areas

Correlations	Medawachchiya	Huruluwewa
Total hardness vs. EC	**0.744***	**0.830***
Total alkalinity vs. EC	0.686	0.641
Chloride vs. EC	0.589	**0.807***
Sulfate vs. EC	0.697	0.576
Ca vs. EC	0.549	0.557
Na vs. EC	0.635	**0.778***
Mg vs. EC	0.618	**0.738***
Total alkalinity vs. pH	0.500	**0.308****
Total alkalinity vs. Total hardness	0.632	0.573
Chloride vs. Total hardness	**0.427****	**0.719***
Sulfate vs. Total hardness	0.505	0.524
Ca vs. Total hardness	**0.471****	**0.715***
Na vs. Total hardness	**0.407****	0.545
Mg vs. Total hardness	0.665	**0.811***
Sulfate vs. Total alkalinity	**0.497****	0.624
Sulfate vs. chloride	0.560	**0.385****
Na vs. Total alkalinity	**0.372****	0.672
Mg vs. Total alkalinity	0.530	0.618
Fluoride vs. Total alkalinity	**0.228****	0.653
K vs. Sulfate	0.592	**0.063****
Na vs. chloride	**0.426****	0.617
Mg vs. chloride	**0.374****	0.550
Na vs. Sulfate	0.530	0.542
Mg vs. Sulfate	**0.477****	0.533
Fluoride vs. Sulfate	**0.126****	0.621
OrthoP vs. K	**0.770***	**0.110****
Mg vs. Ca	**0.356****	0.518
Mg vs. Na	0.501	0.525
WQI vs. Total alkalinity	**0.476****	0.507
WQI vs. sulfate	0.568	0.512
WQI vs. F	**0.153****	0.593
WQI vs. Orthop	**0.740***	0.535
WQI vs K	**0.708***	**0.206****

***Strong positive correlation**
**Weak or no correlation

3.3 Principal component analysis (PCA)

PCA analysis was used as a method of factor extraction. Factors were the preceding estimate of the amount of variation in each groundwater quality parameter. The PCA was carried out on the twenty-four parameters to identify the major variables affecting the groundwater quality during dry months and wet months separately for both study areas. The PCA was conducted using two data sets for each study area to identify the factor loading in wet months and dry months. According to the precipitation data above 50 mm precipitation per month is considered a wet month and below 50 mm precipitation per month is considered a dry month.
The results of the factor loading and eigenvalues of factors in Medawachchiya are shown in Table 4. Two factors were extracted using PCA in dry months and wet months with 36 % and 34 % of total variance respectively in Medawachciya. Factor analysis was conducted using all months together and two factors were extracted with 33% of the total variance.

Table 5 illustrates the factor extraction of Huruluwewa for dry and wet months and using results of all months together. According to that two factors were extracted in dry and wet months with 36% and 37% of the total variance for Huruluwewa. Only one factor was extracted with 24% of total variance when the analysis was conducted using all month's results together. Factor 1 (F1) in Medawachchiya and Huruluwewa indicated strongly and moderately positive loading on EC, total hardness, total alkalinity Ca, Na, Mg, chloride, fluoride and sulfate. This could be due to dissolution of rock particles, calcite and dolomite which were the sources for Ca, Na, Mg, chloride, fluoride, and sulfate from groundwater (Usman *et al.*, 2014). According to the results, F1 can consider a hydro-geochemical influencing factor.

Factor 2 (F2) is strongly and moderately positive loading on K, sulfate, orthophosphate, Na, total alkalinity, fluoride, As, Cd, Se, and Mo. Na, total alkalinity, fluoride, K, and sulfate which can dissolve in groundwater due to the weathering of igneous rock and magmatic rocks in the water. However, total alkalinity and fluoride were loaded only in wet months in Huruluwewa. It may be due to heavy rain and the dissolution of rock particles in

Table 4: Rotated Component Matrix for factor extraction in Medawachchiya

Parameters	Dry months[a]		Wet months[b]		Overall	
	F1	F2	F1	F2	F1	F2
Temp	0.137	0.093	0.073	0.033	0.133	-0.038
EC	**0.856**	0.204	**0.908**	0.166	**0.903**	0.163
DO	0.149	-0.08	-0.062	0.057	0.019	-0.094
pH	0.513	0.132	0.402	-0.068	0.315	0.099
TH	**0.862**	0.036	**0.846**	0.044	**0.777**	0.065
TA	**0.708**	0.351	**0.762**	0.254	**0.657**	0.308
Cl	**0.697**	0.077	**0.544**	0.042	**0.680**	0.066
SO4	**0.663**	**0.508**	**0.638**	**0.515**	**0.680**	0.493
Fl	**0.522**	-0.392	0.436	-0.467	0.373	-0.214
OrthoP	0.228	**0.857**	0.205	**0.770**	0.163	**0.870**
NO3	0.278	-0.279	0.147	-0.181	0.096	-0.065
Fe	-0.04	-0.008	-0.006	-0.107	-0.005	-0.069
Cr	-0.054	0.208	-0.009	-0.036	0.02	0.031
As	-0.096	0.290	0.030	0.042	0.008	0.114
Cd	-0.100	-0.022	0.040	-0.287	0.018	-0.094
K	0.162	**0.912**	0.260	**0.891**	0.192	**0.888**
Ca	0.486	0.165	**0.657**	0.105	**0.549**	0.164
Na	**0.708**	0.07	**0.634**	0.14	**0.760**	0.039
Mg	**0.785**	-0.012	**0.752**	-0.015	**0.757**	-0.011
Zn	-0.183	-0.11	-0.061	-0.251	-0.167	-0.052
Se	-0.154	0.153	0.190	-0.189	0.004	0.045
Mo	0.096	**0.794**	0.112	0.383	0.083	**0.664**
Pb	0.034	-0.133	0.118	0.184	0.079	-0.09
Al	-0.052	0.068	-0.100	-0.191	-0.131	0.051
Eigenvalue	5.818	2.867	5.276	2.789	5.411	2.495
% of varience	24.24	11.945	21.985	11.62	22.544	10.397
Cumulative %	24.24	36.185	21.985	33.604	22.544	32.941

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

F. Factor

Strong loading

Moderate loading

Table 5: Rotated Component Matrix for factor extraction of Huruluwewa study area

Parameters	Dry months[a]		Wet months[b]		Overall
	F1	F2	F1	F2	F1
Temp	0.147	-0.363	0.092	0.104	0.129
EC	**0.878**	-0.072	**0.803**	0.422	**0.882**
DO	-0.135	0.085	-0.085	-0.063	-0.142
pH	0.052	0.067	0.049	0.267	0.091
TH	**0.910**	-0.106	**0.890**	0.320	**0.914**
TA	**0.526**	-0.108	0.299	**0.805**	**0.537**
Cl	**0.782**	-0.122	**0.809**	0.087	**0.788**
SO4	**0.601**	-0.001	0.382	**0.700**	**0.605**
Fl	0.312	0.002	0.082	**0.866**	0.332
OrthoP	0.107	0.004	0.040	0.042	0.059
NO3	-0.222	-0.015	-0.139	0.149	-0.269
Fe	-0.044	0.059	0.156	0.105	0.103
Cr	0.040	0.453	0.222	-0.094	0.080
As	-0.088	**0.796**	-0.149	-0.017	-0.095
Cd	-0.139	**0.693**	0.052	-0.021	-0.080
K	0.114	0.079	0.050	0.051	0.108
Ca	**0.794**	0.029	**0.848**	-0.026	**0.783**
Na	**0.580**	-0.142	0.495	**0.561**	**0.631**
Mg	**0.787**	0.077	**0.707**	0.478	**0.802**
Zn	-0.319	0.263	-0.341	-0.127	-0.403
Se	-0.028	**0.704**	0.037	0.309	0.063
Mo	0.179	**0.567**	0.118	**0.620**	0.189
Pb	0.002	0.014	-0.041	-0.212	-0.096
Al	0.009	0.161	-0.137	0.001	-0.155
Eigenvalue	5.802	2.759	6.135	2.849	5.835
% of variance	24.173	11.492	25.653	11.869	24.314
% of cumulative	24.173	35.670	25.653	37.432	24.314
Extraction Method: Principal Component Analysis.					
Rotation Method: Varimax with Kaiser Normalization.					

F. Factor

Strong loading

Moderate loading

water. Potassium feldspar was usually the main source of K. Dissolution of fertilizers to the water may be the courses for the loadings of orthophosphate, K, As, Cd, Se, and Mo in water. Considering dry months and all months together results orthophosphate, As, Cd, Se and Mo were the most influencing parameters in F2. Therefore, F2 acts as a fertilizer influence factor.

4. DISCUSSION

Temperature, EC, DO, pH, total hardness and total alkalinity were considered as general water quality parameters. Spring water indicated the lowest average temperature, pH, EC, total hardness and total alkalinity values in both study areas. However, the tube wells indicated lowest DO values in both study areas. Dug wells indicated highest mean concentrations of water quality parameters except for temperature. Tube well water was extracted from deeper part of the surface compared to dug wells. The lowest temperature was recorded in springs. Dissolve Oxygen in deep water is relatively less than surface water. Therefore, tube wells indicated lowest average DO concentrations in both study areas. Spring water indicates lower average EC values than dug and tube wells. Water infiltration and dissolution of rock particles of water gives the mineral particles to groundwater which include in dug wells and tube wells. Huruluwewa tube wells and dug wells indicated highest average EC values than Medawachchiya.

Springs indicated the lowest major cations and anions of both study areas except nitrate in the Huruluwewa compared to that of tube wells and dug wells. Water infiltration through the soil and rock particles may lead to increase in the values of above water quality parameters in tube wells and in dug wells.

Therefore, dissolved mineral particles were higher in tube wells and dug wells than in springs. Fertilizer application, infiltration and dissolving phosphate-containing rock in water cause nutrient enrichment in dug wells and tube wells in both study areas. Most of the researchers have studied the water quality in dug wells, tube wells and springs. However, few studies compared the water quality concentrations with each sources (Mahagamage & Manage 2019). Mahagamage & Manage also revealed that lower concentration level of EC (79.00µS/cm -106.33µS/cm) in Medawachchiya, Padaviya and Kebithigollewa sampled springs and 77.60µS/cm-1303.00µS/cm Electrical Conductivity was recorded in wells. Jayasekara *et al*. (2013) revealed that low prevalence of CKDu is noted in communities where water consumes from springs. According to the present study most water quality parameters indicated the lowest concentrations in spring waters than the other two types. Therefore, above statement tally with the present findings.

The EC in the study areas were recorded as extremely high with a variance in the range of 52.5 µS/cm to 3400 µS/cm (Chandrajith *et al*., 2011) in Medawachchiya. Chandrajith *et al*. (2011) indicated that EC ranged from 500 µS/cm to 1500 µS/cm in Medawachchiya compared to Huruluwewa (230 µS/cm to 1129 µS/cm). Gunatilake (2016) revealed that average EC level in the dry zone is 857 µS/cm that comparable with the present study. Paranagama (2013) revealed that total hardness recorded in the Medawachchiya ranged from 60 mg/L as $CaCO_3$ to 685 mg/L as $CaCO_3$ and total hardness is strongly related to the prevalence of CKDu. The results of the present study further confirmed the results of Paranagama (2013). WHO third progress report which was submitted to the Health Ministry of Sri Lanka on 19th February 2012 mentioned that 99% of the CKDu patients have used hard to very hard water for drinking. Therefore, it may be one of the reasons for the prevalence of CKDu. Gunatilake (2016) implied that average total hardness in dry zone is 236 mg/L and varied up to 1104 mg/L as. Chandrajith *et al*. (2011a) noted that total hardness of water from Medawachchiya ranged from 208 to 676 mg/L as $CaCO_3$ and in Huruluwewa it ranged from 15 to 590 mg/L as $CaCO_3$. However highest value recorded for Huruluwewa in the present study is greater than the values recorded by Chandrajith *et al*., (2011b). Chandrajith *et al*. (2011b) revealed that phosphate (PO_4^{3-}) in Medawachchiya ranged from 0.14 to 0.61 mg/L and Huruluwewa ranged from 0.06 to 0.65 mg/L. Jayewardana *et al* (2010) noted that phosphate range in dry zone was 0.5 – 5.00 mg/L. Fairly low levels of fluoride were reported in the study areas due to source of waters such as spring water or mixing of groundwater with irrigation water. Chandrajith *et al* (2012) revealed high fluoride levels in Medawachchiya ranging from 0.52 to 4.9 mg/L and Huruluwewa from 0.02 to 1.68 mg/L. According to the Lasantha (2008) fluoride in Anuradhapura district was in the range of 0.78 to 2.68 mg/L. Chandrajith *et al*. (2011a) revealed that Cd concentration in water was not exceeding the standard levels in their sampling locations in North Central Province Similar results were obtained from the present research.

The Highland complex (HC) predominantly consists of alkaline meta-igneous rocks such as metabasites, charnockitic, granitic gneisses, and politic rocks in Sri Lanka. The superficial deposits found in the Anuradhapura area are the alluvium along major rivers and the regolith which overlies the crystalline rocks (Dissanayake and Weerasooriya, 1985; Panabokke and Perara, 2005 Cooray *et al*., 2019; Mahagamage & Manage 2019).
The Vijayan complex (VC) covers the lowlands of the southeast to the highland series. This type of rock is also found in the Anuradapura region. The VC consists predominantly of gneisses, granitic gneisses, augen gneisses, and migmatites. Soil overburdens of the in-situ weathered rocks are extended from few meters to a tense of meters. The presence of montmorillonite in dry zone soil indicates the slow weathering processes compared to the wet zone (Dissanayake and Weerasooriya, 1985; Dissanayake & Chandrajith 2007; Jayawardana *et al*., 2010; Chandrajith *et al.*, 2020.). The geology of the Anuradhapura area is composed of rock types of the Wanni complex (WC). The high fluoride sites on WC predominantly consist of alkaline meta-igneous rocks such as metabasites, charnockitic, granitic gneisses and politic rocks. The superficial deposits found in the Anuradhapura area are mainly alluvium deposits along major rivers and the regolith which overlies the crystalline rocks (Panabokke and Perara, 2005).

Igneous rock and magmatic rocks contain most of the mineral ions. Therefore, total hardness EC, Ca, Mg were correlated with each other. Runoff from the soil will contribute to the correlation between these ions in water. Total alkalinity is a measure of mainly CO_3^{2-} and HCO_3^--e ions in water. Therefore, total hardness and total alkalinity also are correlated with each other. Agricultural activities contribute to a high concentration of sulfate and orthophosphate in water. Therefore, the above correlations appear in the parameters analyzed in the present study in Medawachchiya and Huruluwewa study areas.

Kumar and Singh (2010) used PCA to analyze factors that influence the water quality in Sanganer Tehsil, Jaipur, India. Two factors were identified through PCA. Factor one includes EC, TDS, Ca total hardness. Mg total hardness, total hardness, chloride, total alkalinity Na, K, and nitrate which originated from anthropogenic causes such as industrial and agricultural pollution. Factor two includes pH and fluoride which originated by natural sources.

Paranagama *et al*. (2013) considered Cl, F, N, P, Ca, Mg, Na, and Cd ions for factor analysis. In the present study other parameters except for F, N and Cd resulted as variables in factors where percentage variance over 10. This is comparable to Paranagama *et al*. (2013). In the collected water samples except for F, P and N resulted as variables in factors with percentage variance over 10 comparable with Paranagama *et al*. (2013) in non-patients' water samples. Gulgundi and Shetty (2018) also indicated that the same factors affected to the groundwater quality in urban Bangaluru, India. Further PCA has revealed the groundwater quality variation is mainly by the dissolution of minerals from rock water interactions in the aquifer, effect of anthropogenic activities, and ion exchanging processes in water. The present study also loaded the same factors which affect the quality of groundwater in the above studies.

5. CONCLUSION

The present study has analyzed water quality parameters in Medawachchiya and Huruluwewa areas in Anuradhapura district Sri Lanka. The quality of water is significantly different from springs, dug wells and tube wells

The groundwater of both areas could be classified in to five clusters. Medawachchiya area with 13% and Huruluwewa with 37% ground water sources were identified as good water sources for drinking purpose. The wells, namely, M03D, M10D, M11S and M16D wells in Medawachchiya and H01D, H03D, H08D, H09T, H12S, H13T, H18D, H21D, H22D and H27D in Huruluwewa were suitable for drinking purpose. Therefore, majority of sampled wells were unsuitable for drinking purpose without any treatment.

It was observed that EC has strong and moderately positive correlation with the Total Hardness, Total Alkalinity, chloride, sulfur, Ca and Mg 32% and 24%. Cumulative variations appear in Medawachchiya and Huruluwewa areas to be from water quality parameters associated with natural processes corresponding to dissolution of rock and agricultural activities such as non-point sources. Further, the hydro-geochemical and agro-chemical factors may influence the water quality status in both study areas.

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