

WATER QUALITY PARAMETERS IN RELATION TO CHRONIC KIDNEY DISEASE IN SRI LANKA

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Abstract

In Sri Lanka, high concentrations of certain water quality parameters in drinking water are assumed to be causing Chronic Kidney Disease (CKD). North Central Province (NCP) in Sri Lanka reports the highest number of CKD patients and mortality rates. The reported research herein concentrates on re-examining diverse causative factors identified by previous researchers on CKD and analysis of water quality in samples from shallow wells supplying drinking water to CKD patients and non-patients in NCP. The samples were tested for a number of parameters such as anions, cations, and heavy metals. These include Cd, Na, Ca, F and Cl which previous researchers have suggested as causative factors for CKD. The preliminary analyses of data indicated majority of water quality parameters collected from the study area did not exceed the WHO drinking water quality standards. The critical water quality parameters that could cause the CKD were investigated using Factor Analysis techniques. From the water samples collected from the CKD Patients the parameters of Na, Cl, Mg, F and Ca could be grouped into one Factor and identified as hydro-geologically originating. Another Factor which could be due to nutrients from fertilizer was identified consisting of N and P whereas Cd was grouped into a single Factor. In contrast, the water quality parameters in water samples collected from CKD Non-Patients were different and could not be clearly grouped into any special category.

Keywords: Chronic Kidney Disease (CKD), North Central Province (NCP) in Sri Lanka, CKD Patients, Water Quality Analysis, Statistical Analysis, Factor Analysis

1. Introduction

Chronic Kidney Disease (CKD) has become a serious medical concern in Sri Lanka. North Central Province (NCP) in Sri Lanka reports the highest number of CKD patients and mortality rates due to CKD. NCP consists of two administrative divisions namely Polonnaruwa and Anuradhapura districts. Anuradhapura District reports the highest number and Polonnaruwa District reports the second highest number of CKD patients (Poulter and Mendis, 2009). It is estimated approximately 3000 had died between the years of 2003 to 2008 (Edirisuriya, 2010) by CKD and the present number of patients estimated to be around 15,000 (Johnson et al. 2012).

More than 65% of the people in NCP depend on basic farming for living (Lasantha, 2008). Anuradhapura and Polonnaruwa districts fall under dry agro-ecological zone of Sri Lanka with an average annual precipitation of 960mm. Most of the precipitation is brought by the North-East monsoonal rains which fall in the months from October to March. During the dry period lasting approximately for eight months, farmers depend on surface water which include more than 3000 medium and large scale irrigation tanks in NCP (Karunaratne, 1983). NCP has hard rock or crystalline basement complex of rocks which are well known for their very limited shallow groundwater aquifers (Panabokke, 2003). Groundwater is the main drinking water resource and more than 85% of the drinking water requirements for the rural communities which are obtained from shallow and deep wells (Lasantha, 2008). The shallow groundwater sources are known to benefit by seepage from small tank cascade systems located upstream (Panabokke, 2003).

One of the suspected chemical contaminants to cause CKD in Sri Lanka is Fluoride (F). High Fluoride levels (above 1.5mg/L) in well water in the NCP had been observed as far back as 1976 and subsequent studies have shown that 40% of wells in NCP were rich in Fluoride and a number of 456 deep tube wells in Anuradhapura district has also been found with Fluoride contents ranging from 0.78 to 2.68 mg/L (Lasantha, 2008). Previous studies have shown even in low doses (of 7.5mg) of F over long periods of time (example 100 days) can make morphological changes in kidneys (Manocha et al., 1975) and also chronic exposure to F leading to inflammatory response in kidneys in mice (Greenberg, 1986).

Another cause of CKD explained by Chandrajith et al. (2011) is Na/Ca ratio in drinking water with high levels of Fluoride. Accordingly, with high Na in the presence of F in water is said to form Sodium Fluoride (NaF) which is soluble in water which does not cause Kidney Tubular Damage. On the other hand with high Ca in the presence of F, Calcium Fluoride (CaF_2) is said to form which is insoluble in water causing Kidney Tubular Damage (Chandrajith et al. 2011). Thus high Ca concentrations compared to Na concentrations in drinking water are said to be influencing CKD. They have further shown a Na/Ca ratio in a range of 1.6 to 6.6 in the CKD endemic areas and a range between 35 and 469 in the non-endemic regions.

This is supported by the fact that in Anuradhapura District, 34% of the wells exceed the maximum desirable level of 100mg/L of Ca in drinking water and also 8% of the wells exceeding the maximum permissible level of 240mg/L (Lasantha, 2008), leading to high Ca concentrations in water.

Heavy metal pollution is a recent concern for CKD in Sri Lanka and Arsenic and Cadmium are mainly suspected as heavy metal pollutants (Johnson et al. 2012) suspected to be originating from agrochemicals (Wijewardena, 2012). A research by Bandara et al. (2008) had shown that Cd concentrations between 0.03 to 0.06 mg/L in dissolved form and 1.78 to 2.45 mg/Kg in sediments in certain irrigation tanks of NCP. Since then Chandrajith et al. (2011) have shown that there is hardly any Cd in drinking water sources in NCP.

A relationship between Fluoride and Aluminum utensil usage have also been established by Herath et al. (2005) concluding Aluminum and Fluoride in combination could be a another factor to cause CKD in areas with high Fluoride in groundwater. They have concluded that Aluminum leaching is higher when the Aluminum pots are used for cooking using acidic ingredients.

Research objectives of the current study included identifying main sources of contaminants of drinking water which are suspected to cause CKD. The paper reveals in its introduction, the background into the problem. The materials and methods applied for chemical and statistical analyses are also described. Descriptive Statistical results are shown in graphical form comparing the chemical parameters with WHO recommended levels. The Factor results showed the chemical parameters of water which are correlated to each other in the Patient and Non-Patient samples. Conclusions were based on the Factor and the Descriptive statistical results.

2. Description of Sample Collection

A list of CKD patients was obtained from the Health Registry of CKD endemic area. Out of them random patient households were visited and water samples obtained directly from their drinking sources. They were named as “Patient” samples. From the same area, random households with members not having CKD were selected and drinking water samples were obtained from their water sources. They were named as “Non-Patient” samples. Those Patient and Non-Patient drinking water sources were shallow wells but two Patient samples were drawn from tube wells. Those sample locations were Medawachchiya Village Division in Anuradhapura District and Medirigiriya Village Division in Polonnaruwa District. Another set of samples were obtained from a CKD free area namely Gampaha District from shallow wells used for drinking. When choosing sampling water sources, those which have been used for more than 10 years for drinking by CKD patients or non-patients were selected. Sample collection was carried out between December 2010 and August 2011. The patient and non-patient water samples were grouped as: Polonnaruwa Patients (P-POL) and Non- Patients (NP-POL); Anuradhapura Patients (P-ANU) and Non- Patients (NP-ANU) making four total groups

from CKD endemic area and another Control group from CKD free area of Gampaha (C-GAM). Those five groups were considered in statistical analysis (Figure 1).

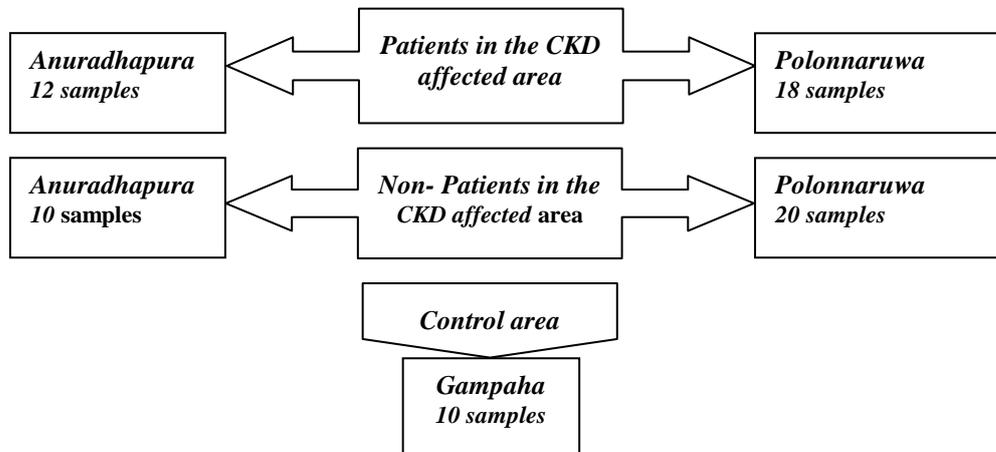


Figure 1: Water Sample Collection Locations

3. Chemical Analysis

Chemical parameters of water samples were tested in a commercial laboratory namely SGS Laboratories Pvt. Ltd in Colombo. Preservatives of HNO₃ and H₂SO₄ were added to the samples before transporting them to the lab for chemical analysis. Chemical parameters analyzed were Chloride (Cl), Fluoride (F), Nitrate (N), Phosphate (P), Calcium (Ca), Magnesium (Mg), Sodium (Na) and Cadmium (Cd). Other Chemical parameters were not analyzed due to resource constrains. Test Protocols used by the lab include: 3120 APHA 21st ED for Cadmium, Sodium, Magnesium and Calcium; 4500 APHA 21st ED for Fluoride, Chloride and Total Phosphorus; 4500 APHA 21st ED for Nitrate.

After chemical analysis, the levels of parameters in each sample category were compared with World Health Organization (WHO) standards. WHO standards were used for comparison of chemical variables as those values are the basis for regulation and guidelines for drinking water in developing and developed countries.

4. Factor Analysis

Factor Analysis was carried out to find whether any of the water quality parameters can be grouped into factors depending on their interdependency as it is used to identify factors that statistically explain the variation and co-variation among variables (Green and Salkind, 2005). This technique is applied by many researchers to characterize and evaluate groundwater and surface water quality data (Kumar and Singh, 2010; Guan et al. 2005; Yidana, 2008). Factor Analysis identifies a group of parameters correlated to each other and combine them into factors which are independent of variables in another factor. Factor Analysis was carried out

for all Patient and Non-Patient data from the CKD endemic area of Anuradhapura and Polonnaruwa. Factor Analysis was not carried out for data from the Control area (Gampaha).

5. Results and Discussion

5.1 Descriptive statistics

Descriptive statistical results included average, median, maximum and minimum. The maximum and average values of each chemical parameter in each sampling group were compared with WHO recommended water quality standards (Figure 2).

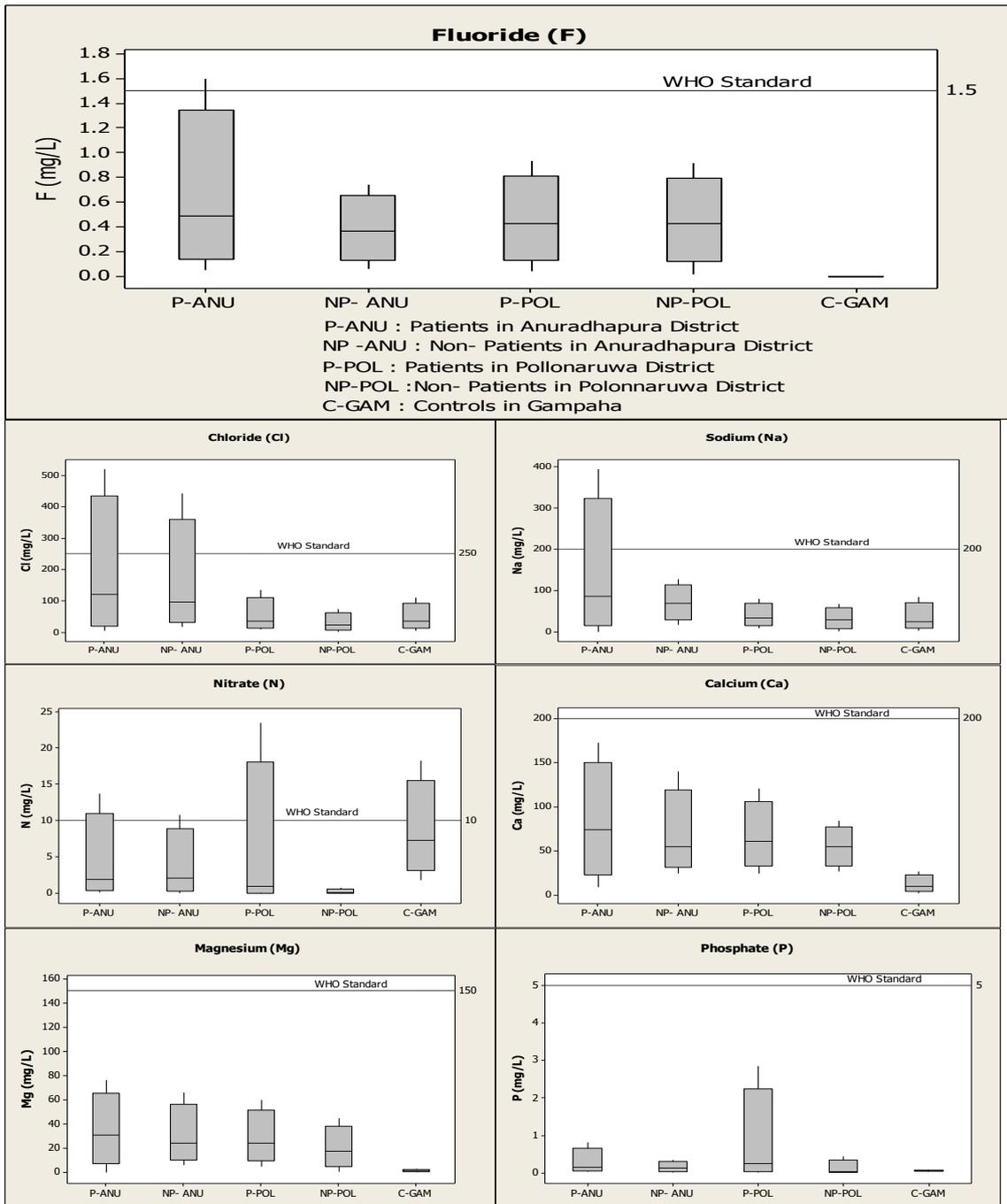
Although the literature suggests that F concentrations are high in the NCP of Sri Lanka, only one sample (out of 60 samples collected for the CKD endemic area) of Anuradhapura Patient exceeded the WHO standard of 1.5ml/L. The samples from the Control area (Gampaha) had the lowest levels of F.

In contrast to F, for Chloride (Cl) five out of twelve Patient samples and one out of ten Non-Patient samples exceeded the WHO standard (250ml/L) in Anuradhapura. However, none of the samples in Polonnaruwa have exceeded the WHO standard. Furthermore, the concentration levels of Cl in Gampaha Control area was almost the same as in samples collected from the Polonnaruwa District. With regard to Na, two Anuradhapura Patient samples exceeded the recommended WHO standard of 200mg/L but Anuradhapura Non-Patient samples did not exceed this limit. Also none of the samples from Polonnaruwa exceeded the WHO limits for Na and they were almost equal to maximum and minimum levels of Na in Control area samples.

Calcium (Ca), Magnesium (Mg) and Phosphate (P) levels in drinking water samples showed similar results compared to WHO standards where the average or maximum levels of all sample groups did not exceed the WHO standards of 200mg/L for Ca, 150 mg/L for Mg and 5mg/L for P.

In contrast to all other variables, Nitrate (N) concentration of some Anuradhapura Patient and Non-Patient samples as well as Polonnaruwa Patient samples in some locations have exceeded the WHO standard (10mg/L), but none of the Polonnaruwa Non-Patient samples have exceeded this limit. In the control area of Gampaha N levels in two out of the ten samples have exceeded the WHO standard. Gampaha is mainly an urbanized residential area which could be the reason for this.

None of the drinking water samples in Anuradhapura District had Cadmium (Cd). However both Polonnaruwa Patient and Non-Patient samples contained Cd, but they did not exceed the WHO permissible level of 0.005mg/L in both the maximum and averages values. In the Control area in Gampaha Cd was not detectable in any of the water samples.



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Figure 2: The average, maximum and minimum values of variables F, Cl, Na, Mg, Ca, N, P and Cd in the five sampling groups compared to WHO recommended limits

5.2 Cross-correlation matrix

Initially a cross-correlation analysis was carried out to determine whether the Factor Analysis could be carried out with the obtained data. According to Kaiser (1974) there has to be cross-correlation coefficients of above 0.3 to proceed with the Factor Analysis. The correlation

matrices given in Tables 1 (Patients) and 2 (Non-Patients) in CKD endemic area (Anuradhapura and Polonnaruwa) depict a number of cross-correlation coefficients above 0.3 which indicated Factor Analysis could proceed.

Table 1: The correlation matrix between variables in Patient data

<i>Parameter</i>	<i>Cross-correlation coefficient</i>							
	<i>Cl</i>	<i>F</i>	<i>N</i>	<i>P</i>	<i>Ca</i>	<i>Mg</i>	<i>Na</i>	<i>Cd</i>
<i>Cl</i>	1.00							
<i>F</i>	0.60	1.00						
<i>N</i>	0.08	0.02	1.00					
<i>P</i>	-0.13	-0.04	0.74	1.00				
<i>Ca</i>	0.83	0.45	0.21	-0.04	1.00			
<i>Mg</i>	0.73	0.72	0.26	-0.01	0.74	1.00		
<i>Na</i>	0.87	0.75	0.02	-0.12	0.66	0.70	1.00	
<i>Cd</i>	-0.17	0.02	-0.08	0.21	-0.23	-0.02	-0.14	1.00

Table 2: The correlation matrix between variables in Non-Patient data

<i>Parameter</i>	<i>Cross- correlation coefficient</i>							
	<i>Cl</i>	<i>F</i>	<i>N</i>	<i>P</i>	<i>Ca</i>	<i>Mg</i>	<i>Na</i>	<i>Cd</i>
<i>Cl</i>	1.00							
<i>F</i>	0.08	1.00						
<i>N</i>	0.69	-0.12	1.00					
<i>P</i>	0.07	-0.06	0.01	1.00				
<i>Ca</i>	0.66	0.45	0.55	-0.18	1.00			
<i>Mg</i>	0.76	0.46	0.43	0.02	0.72	1.00		
<i>Na</i>	0.49	0.22	0.12	0.31	0.13	0.60	1.00	
<i>Cd</i>	-0.03	0.04	-0.06	-0.06	-0.12	-0.07	-0.07	1.00

5.3 Factor extraction

In Factor Analysis it is important to identify the number of significant Factors that could be extracted from the data set in hand. The Eigen Value and the Percentage Variance are good indicators in deciding on how many factors to further analyse. Factors having an Eigen Value above 1 and a Percentage Variance above 10% are considered for further analysis as Factors (Green and Salkind, 2005). The Eigen values are given by the Scree Plots depicted in Figure 3 for data obtained from Patient and Non-Patient data sets respectively from CKD endemic area. Accordingly three Factors were extracted from each data set.

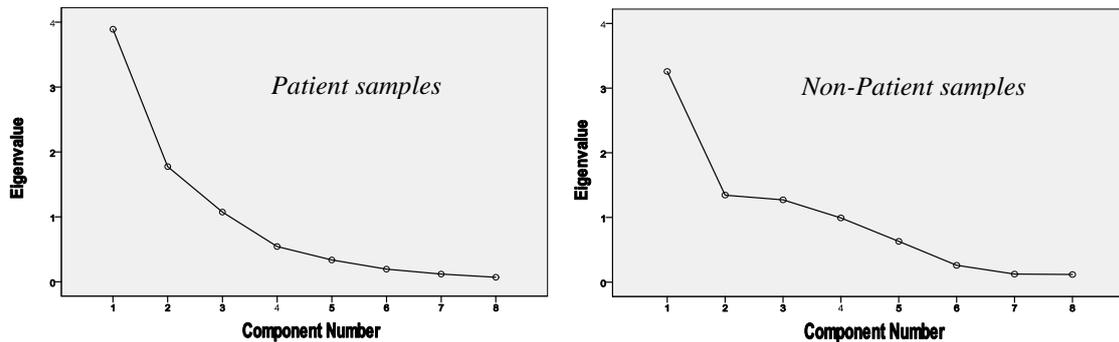


Figure 3: The Scree plots for Patient and Non-Patient samples showing the relationship between the Factors to be extracted and Eigen Values

The Principal Component Analysis was used as the Factor Extraction method. For the Patient data, the results showed that variables of Na, Cl, Mg, F and Ca fall into one Factor showing a strong interdependency between these parameters. This was followed up by N and P falling into the second Factor and Cd falling into the third Factor (Table 3 and Figure 4).

According to the Factor Analysis results summary of Non-Patient data it was observed that N, Cl, Mg and Ca, falling into one factor, P and Na falling into the second Factor, and F falling into the third Factor (Table 3 and Figure 4).

In Factor Extraction the reliability of the variables in a Factor is measured by an indicator namely Cronbach's Alpha value which measures the correlation between the variables in each Factor. High Cronbach's Alpha value indicates a high reliability of the parameters in the Factor. Cronbach's Alpha value of above 0.7 is known to be acceptable indicating the reliability of the variables in the Factor (Kaiser, 1974). The Cronbach's Alpha values obtained for each Factor in both data sets are given in Table 3. According to research results the Factor 1 in Patient samples had a Cronbach's Alpha value of 0.74 indicating all the variables in Factor 1 are highly correlated.

The Eigen Value and the Percentage Variance are given in Table 3. For the Factor 2 in Patient data with variables N and P the Cronbach's Alpha was only 0.30 indicating comparatively less correlation of the variables to its Factor. However Percentage Variance for this factor was 22.2% and the Eigen value was 1.78 which showed that it is a significant factor to be considered in Patient data.

It is said to be not preferable to define factors by a single variable (Green and Salkind, 2005). Conversely for the Patient data, in Factor results, Cd itself could be extracted as a Factor because it had an Eigen Value of 1.07 and a Percentage Variance of 13.42. Thus Cd itself could be extracted as a Factor in Patient data.

Table 3: Factor extraction results of drinking water samples of CKD Patient and Non-Patient data

Group Category	Factors extracted	Variables in each Factor	Cronbach's Alpha value	Initial Value	Eigen Value	Percentage Variance (%)
Patient data	Factor 1	Na, Cl, Mg, F, Ca	0.74	3.89		48.64
	Factor 2	N, P	0.30	1.78		22.18
	Factor 3	Cd	-	1.07		13.43
Non-Patient data	Factor 1	Mg, Ca, Cl, N	0.55	3.26		40.72
	Factor 2	P, Na	0.004	1.35		16.82
	Factor 3	F	-	1.27		15.91

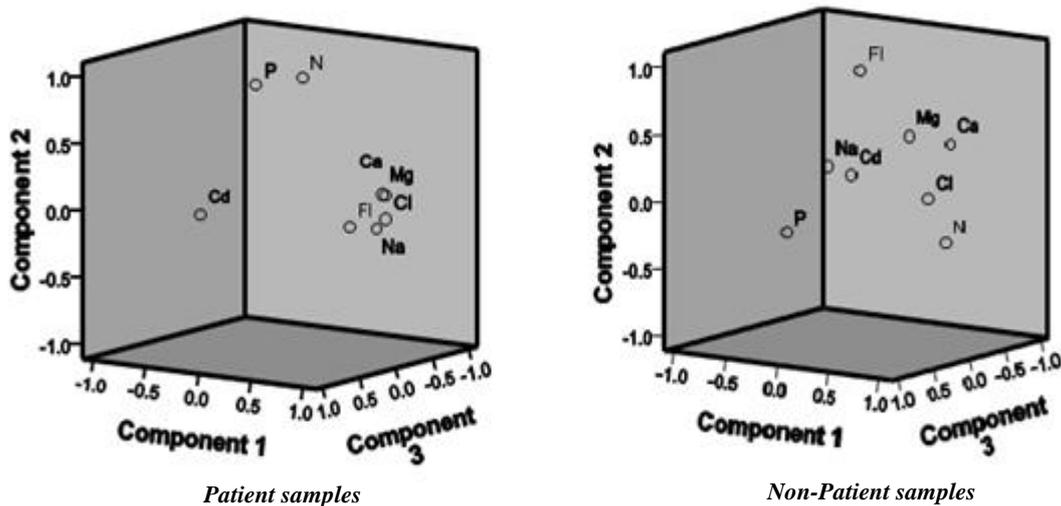


Figure 4: Factor Extraction Results of Patient and Non-Patient data

With regard to Patient samples, the variables of Na, Cl, Mg, F and Ca having high correlations are clearly identifiable in Factor results where they go together in one Factor. All these chemical parameters could be naturally occurring in water. The parameters of N and P in the second Factor of Patient samples could be originating from fertilizer leaching into water. Those Factors were evident in correlation analysis with Cross-correlation Coefficients above 0.60. In contrast the Factor variables (Mg, Ca, Cl and N) in the Non-Patient samples were different to those variables extracted from the Patient samples. This can be explained by the smaller Cross-correlation Coefficients in the Cross-correlation matrix (Table 2). Furthermore, Cd was a dominant variable in Patient samples. On the other hand F as a single variable was a significant Factor in Non-Patient samples. As reported earlier Chandrajith et al (2011) have shown that Na/Ca ratio in F rich areas could influence CKD. Similarly Bandara et al (2008) also have shown Cd could be a causative factor of CKD. The findings from the current study are consistent with these findings by Chandrajith et al (2011) and Bandara et al. (2008) and therefore further research is important to identify the actual causes of CKD.

6. Conclusion

According to Descriptive Statistical analysis results none of the average concentration levels of water parameters exceeded WHO recommended values for all five sample pools. Although literature suggests that the Fluoride concentrations are high in North Central Province of Sri Lanka, only one sample out of 60 samples from the CKD endemic area had F concentrations above the WHO recommended value for Drinking water. None of the variables showed concentration levels above WHO standards in Gampaha Control area except for Nitrate in two out of ten samples.

According to Factor Analysis results, three Factors were identified in Patient samples which were distinctively different from the Non-Patient samples. Accordingly Na, Cl, Mg, F and Ca in Patient' samples were grouped into one Factor and could be identified as hydro-geologically originating. Other Factor in Patient samples with N and P could be due to agricultural inputs leaching into water.

With regard to Cd, none of the Anuradhapura CKD Patient samples contained Cd. Therefore in Factor results, the Factor consisting of Cd had been the due to water contaminated with Cd obtained from Polonnaruwa Patient samples. Therefore in Polonnaruwa, Cd can be considered as a significant Factor by itself acting as a pollutant of drinking water sampled.

In contrast to Patient Factor groupings, Non-Patient Factors could not be grouped clearly according to a specific source of generation.

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