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Technical Report

Evaluation of Well water quality with special emphasis on Principal Component Analysis (PCA) at Maharagama, Sri Lanka

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In the present study 800 well water samples were collected from five Grama Niladhari (GN) divisions situated in Maharagama, Sri Lanka. The area is highly populated and urbanized with a very shallow ground water table. Ground water quality was analyzed and compared with different GN divisions identifying well water contamination pattern using Principal Component Analysis (PCA). Eighty wells were sampled monthly using simple random sampling method from January 2012 to October 2012. PCA analysis identified three clusters, Navinna GN division as cluster 1' with high electrical conductivity values, Jambugasmulla, Wijerama and Gangodawila South B together as 'cluster 2' with high organic pollution and Wattegedara being the highest polluted GN division as 'cluster 3'. Overall results indicated that water quality of the area is deteriorated with risk of potential water borne diseases and all parameters tested were far above the SriLanka Standard Institute standards given for drinking water quality.

Key words: Well water, Contamination, Water pollution, PCA analysis, dumping site

1. Introduction

The quality of water, whether used for drinking, domestic purposes, food production or recreational purposes has an important impact on health1). 40% of Sri Lankan population has been provided water supply facilities and 59.4% is depending on other sources such as wells, tube wells, streams and rivers etc. Including 10% on unprotected sources[2)]. Groundwater contamination adversely affects the individuals who consume well water. Groundwater has been naturally very clean because of its filtering effect; however it can become polluted with nutrients and toxic chemicals when surface water carrying these substances drains into the groundwater environment[3)]. In Sri Lanka, ground water is mainly used via well water. Wells are a great access route to the shallow ground water table. When surface water is contaminated with sewage or human and animal excreta, there's a high chance that ground water can be polluted with pathogenic microorganisms indicated by presence of coliform bacteria as well[4) 5)].

The present study was carried out in an area where 70% of the population uses well water as their staple water supply. Therefore, assessing the quality of well water where many lives are dependent upon, is of vital importance. The study area is a highly urbanized area with a population density > 1600km^{-2} and continuously populating with expected population is about 253047 by 2021[6)] (**Fig. 1**). Also the area is having many

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government and non-government industries and institutes where these industries and domestic activities generate considerable quantities of municipal solid wastes per day but unfortunately, there is no proper treatment and disposal facility for the management of the wastes from these areas. The wastes are disposed in a disorganized manner, at several dumpsites within the streets. The previous major solid waste dumping site at Navinna which is now converted into a playground was situated in the area and some other major pollutant sources are also available. There are no municipal sewage systems and only privately owned sewage pits are scattered in the study area[6]. Previous authors have recorded contamination status of well water in the study area in terms of coliform, heavy metals and other chemical parameters as well[7) 8) 9)]. The present study was carried out as a continuation to find out the current overall well water quality status in the area with special emphasis of PCA analysis.

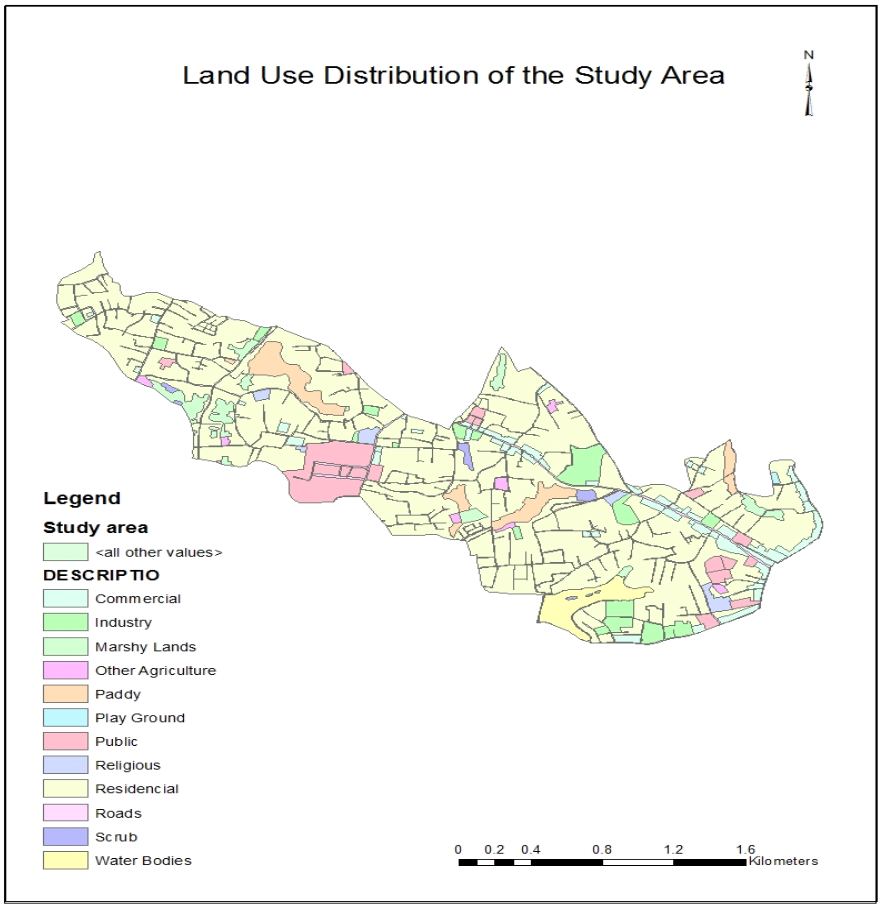

Fig. 1 Land use pattern of five selected GN divisions in Maharagama

The complexity of water quality as a subject is reflected in various types of measurements[10]. In view of the past data that daily drinking and domestic water in the area, is of questionable quality[7)-9)], there was a need to understand any pattern of water quality among the several GN (Grama Niladhari) divisions studied to take actions for the water quality issue. Principal Component Analysis (PCA) of multivariate techniques are therefore adopted for the study with the usage of other statistical analysis such as One sample t test, Two sample t test, One Way ANOVA, etc.

A literature review on principal components analysis, a technique that was formerly used in the field of hydrology, has shown its appropriateness for water quality data, as confirmed by some recent case studies[11)-14)].When considering water quality data, principal component analysis has been used to find the hidden relationships among them[15].

Multivariate analysis techniques are very useful in the analysis of data corresponding to a large number of variables[10]. Analysis via these techniques produces easily interpretable results[14) 16)]. Multivariate data consists of observations on several variables for a number of samples (also called sample vectors, or individuals) and a wide variety of multivariate analysis techniques is available. The choice of the most appropriate technique depends on the nature of the data, problem, and objectives. The underlying theme of many multivariate analysis techniques is simplification and in other words, it is desired to summarize a large body of data by means of relatively few parameters. One fundamental distinction between the techniques is that some analyses are primarily concerned with relationships between variables, while others are primarily concerned with relationships between samples. Techniques of the former type are called variable-directed, while the latter are called individual-directed (sample-directed) multivariate analysis. If the variables arise on an equal footing with more than two variables, principal components analysis may be appropriate. This technique aims to transform the observed variables to a new set of variables which are uncorrelated and arranged in decreasing order of importance. The principal aim is to simplify the problem and to find new variables (principal components) which make the data easier to understand[14].

PCA is used to search new abstract orthogonal eigen-values which explain most of the data varies in a new harmonize structure[17]. Each principal component (PC) is a linear combination of the original variables and describes different source of information by eigenvalue based on the decomposition of the covariance/correlation matrix[18]. PCA is designed to modify the observe variables into uncorrelated variables of linear combinations of the original variables called "principal components"[17),16)] as well as to investigate the factors which caused variations in the observed datasets[14]. The principal component therefore provides information for interpretation and better understanding of the most meaningful parameters which describes the whole data set through data reduction with a minimum loss of the original information[10].

The aims of the study were (1) to evaluate the well water quality of the study area by means of physico chemical and microbiological parameters and (2) to compare the well water quality among five selected GN divisions using a few significant and interpretable PCA patterns.

2. Materials and Methods

Ground water samples were collected from Jambugasmulla, Navinna, Wijerama, Gangodawilla South B, and Wattegedara including University of Sri Jayawardhenapura premises to cover five Grama Niladhari divisions situated in Maharagama, Sri Lanka (**Fig. 2)**. Eighty wells were sampled monthly in day time from 8.30AM to 5.30PM (In two consecutive days) using simple random sampling method from January 2012 to October 2012 covering 800 well water samples for microbial and physico-chemical parameters by standard analytical methods with reference to SLSI drinking water standards (**Fig. 2; Table 1**).

Table 1 Number of sampling locations in each GN division

Name of GN divisions	Number of sampling locations
Jambugasmulla	13
Navinna	14
Wijerama	10
Gangodawila south B	20
Wattegedara	23
TOTAL	80

The number of sampling locations in each GN division depended on the land area and availability of wells in the division. Well water samples were collected using a clean plastic bucket (five liter capacity) and samples were collected separately for both microbiological, physico-chemical water quality analysis and three replicate samples were taken from each well. Before collecting samples, the bucket was pre cleaned using water with the well itself and then wiped with 70% alcohol. The bucket was then let dry for a while and water samples were taken. For physico chemical analysis, water samples were collected into light and dark glass stoppered bottles for Dissolved

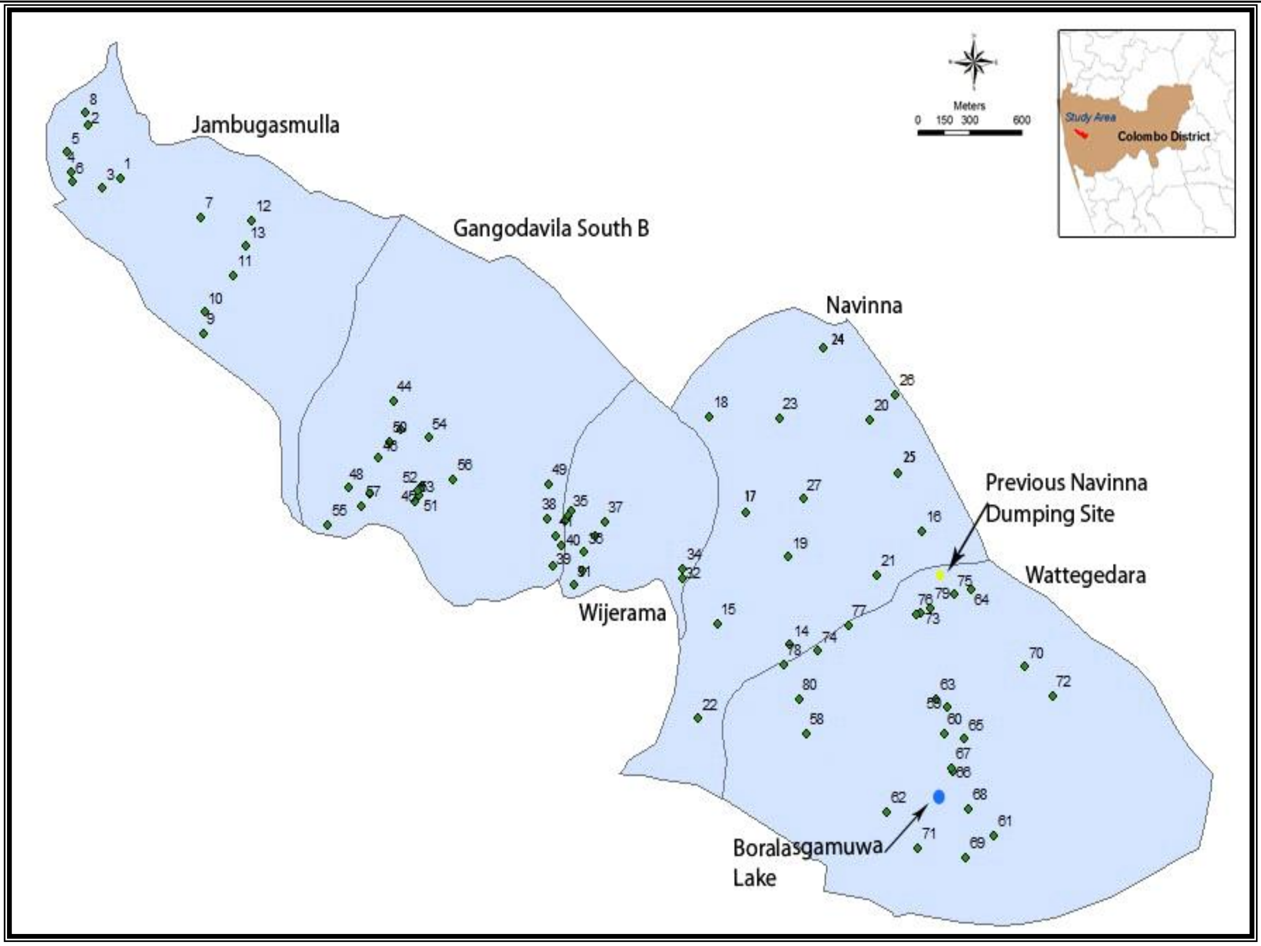

Fig. 2 The sampling locations within the study area

Oxygen (DO) and Biological Oxygen Demand (BOD) measurements. All other samples were collected into clean plastic cans & glass bottles according to the standard test requirements. pH, temperature and conductivity were measured at the site itself using pH meter (3110A-SET 2, WTW Co., Weilheim, Germany), Thermometer (Immersion, Philip Haris, England) and Conductivity meter (3110- SET 1,WTW Co., Weilheim, Germany) respectively. For microbiological analysis, samples were collected in sterilized (120^0 C, 15 minutes) 270 mL glass stoppered bottles and 1L glass bottles covered with aluminum foil. When collecting samples from taps (well water was taken via a tap line at some locations when well was been covered permanently) water was allowed to flow for 30 seconds, then tap was cleaned mechanically using 70% alcohol and subsequently were flamed until completely dry. Then again water was let to run for another 30 seconds before samples were collected into glass bottles. Water samples were placed in ice box (insulated) during transportation to laboratory and kept at -4 °C until analysis. Water samples for physico chemical analysis were filtered with GFC filter papers to remove suspended particles after taken to the laboratory and analyzed within 48hours for chemical parameters. For microbiological analysis, samples were examined immediately (within 4 hours) on arrival at the laboratory. Nitrate was measured by a colorimetric method (Sodium- salicylate method with a wave length of 420nm). Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) were measured using Standard Winkler method. Chemical Oxygen Demand (COD) was measured with Closed-Reflux method. Standard Multiple Tube Fermentation method[22] was used to detect total coliform count and fecal coliform count. Standard methods were used to prevent contamination when collecting and transporting samples to the laboratory according to standard methods[19]. Water samples were analyzed using standard methods[20),21]. The laboratory results were evaluated using multivariate statistical techniques of PCA for selected parameters using Primer version 5.1 statistical software and SPSS-18. Twelve variables were selected such as water temperature, conductivity, salinity, pH, DO, BOD_5, COD,TDS, nitrate, total phosphate, total coliform and fecal coliform. Five principal components were identified considering the eigen values greater than one. Since the variables are in widely different units (mgL^{-1}, pH, ˚C, etc.), the standard variants and correlation matrix was used to conduct the analysis[13),14]. After computing the variances (eigenvalues) and principal components (eigenvectors) of a correlation matrix, the usual procedure is to look at the first few components which, account for a large proportion of the total variance.

3. Results and Discussion

The principal components, PC-1 and PC-2 contribute about 74.8% of the total variance in the data (**Table 2**). Mean ranges of nitrate (0.64-77.31 mgL^{-1}), Total phosphate (0.07-2.68), pH (4.11-7.14), conductivity (114-70000 μScm^{-1}), salinity (0-0.1 μScm^{-1}), BOD_5 (0.03-19.40 mgL^{-1}), DO (0.01-5.89 mgL^{-1}) and COD (0.14-64.13 mgL^{-1}) were recorded respectively.

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Table 2 Summary of the Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	5.39	44.9	44.9
2	3.59	29.9	74.8
3	2.19	18.2	93.0

The first principal component, as given in Table 2, has variance (Eigenvalue) 5.39 and accounts for 44.9% of the total variance. The coefficients listed under PC1 in Table 3 shows how to calculate the principal component scores:

PC1 = -0.151 pH + 0.383Temp. - 0.039 Cond. + 0.395 Salini. + 0.366 Nitrat. + 0.133 Phosp. + 0.420 COD - 0.309 DO + 0.383 BOD5 + 0.303 TSS + 0.086 TC + 0.058 FC

PC1 is contributed by COD, BOD_5, Water temperature, Salinity, Nitrogen - Nitrate and Total Suspended solids even though there is no parameter value obtained more than 0.5. The second principal component has variance 3.59 and accounts for 29.9% of the data variability. It is calculated from the original data using the coefficients listed under PC2. PC2 is strongly contributed by Fecal coliform. Furthermore Total coliform, Conductivity and pH values are contributed for PC2. Together, the first two and first three components represent 74.8% and 93.0% of the data variability respectively, of the total variability. Thus most of the data structure can be captured in two or three underlying dimensions. The remaining principal components account for a very small proportion of the variability and are probably unimportant. It showed that majority (71%) of the wells in the present study had below safe pH level (<6.5 - 7.0) (Acidic condition). Highest desirable level of pH according to SLSI standards is in 7.0-8.5 range and maximum permissible level is in 6.5-9.0 range. Only 8% sampling locations recorded safe pH value. The lowest pH value was recorded from Navinna *Eigenvectors* (Coefficients in the linear combinations of variables making up PC's)

Table 3 Correlation matrix of principal component analysis

Variable	PC1	PC2	PC3
pH (25°C)	-0.151	-0.439	-0.190
Water temperature (°C)	0.383	0.177	0.209
Conductivity ($mScm^{-1}$)	-0.039	0.470	0.077
Salinity	0.395	-0.153	0.152
Nitrogen - Nitrate	0.366	-0.015	0.272
Phosphate	0.133	-0.100	0.582
COD (mgL^{-1})	0.420	0.069	-0.115
Dissolved oxygen (mgL^{-1})	-0.309	-0.073	0.457
BOD5 (mgL^{-1})	0.383	0.088	-0.143
Total suspended solids (mgL^{-1})	0.303	-0.175	-0.386
Total coliform count/100 mL	0.086	-0.457	0.281
Fecal coliform count/100 mL	0.058	-0.515	-0.086

which was 4.11. The highest Conductivity value (70000 μScm^{-1}) was recorded from the same GN division Navinna whereas highest desirable level of conductivity according to SLSI standards is 750 μScm^{-1} and maximum permissible level is 3500 μScm^{-1}. The reason for this massive increment beyond the standards might be the high ion concentration in the water table and may be related to the previous Navinna dumping site. Even after ceasing the site from garbage dumping and converting it into a playground, there was no proper removal of hazardous waste products dumped at the site. Therefore, earlier absorbed pollutants have leached into the ground water and still might be available since these pollutants are not degraded in a short time. Previous authors found that several heavy metals were also present in the water table around Navinna dumping site[7)]. Except Navinna in almost all other GN divisions conductivity values were safe for the drinking purposes (81.3%) obtaining a significant difference among Navinna and other GN divisions ($p<0.001$). Salinity and Temperature were in safe ranges for drinking purposes in all five GN divisions. Infants, upon ingesting too much Nitrate, can develop methemoglobinemia, or “blue baby syndrome” which can be fatal[23)]. When considered about Nitrate distribution in well water in the selected five GN divisions, minority (11%) of the wells had a safe NO_3^- level and suitable for drinking purposes. But majority (89%) had a non-safe level and One way Anova confirmed that this non safe level of Nitrates were significantly high ($p<0.001$). In fact this situation is alarming since some wells in the study area exceeded 60 mgL^{-1} Nitrate level although the recommended $N0_3^-$ level is 45 mgL^{-1} according to SLSI standards and 10 mgL^{-1} according to WHO standard. One Way Anova confirmed that Nitrate levels among GN divisions were not significantly different ($p=0.074$) indicating all five GN divisions have a similar level of Nitrate concentration in well water pool. However Wattegedara GN division had the highest mean NO_3^- level exceeding 40 mgL^{-1}. Nitrate may arise from the excessive application of fertilizers or from leaching of wastewater or other organic wastes into surface water and groundwater[24)]. Results of the current study also convinces this fact as there’s a higher usage of fertilizers and liberal use of organic manure for home gardens in the study area specially Wattegedara, Jambugasmulla and Gangodawila south B, water. More importantly improper usage and planning of soakage pits and latrines may further contribute to excessive nitrate levels[25)]. This situation exactly agreed with the study area where blue baby syndrome (Methamoglobinaemia) has been recorded[26]. This condition is critical for the infants and weaker adults so that the Nitrate concentration should be carefully monitored and controlled. This was the reason to use WHO standard as the drinking water standard for Nitrate concentration which is much lower (<10 mgL^{-1}) than SLSI standards (<45 mgL^{-1}). Due to the high well water pollution status in the area, this high COD (Chemical oxygen demand) level exceeding the standards is a possibility and it indicates the higher level of organic pollution in the water. Maximum permissible level of COD according to SLSI standards is 10 mgL^{-1}.When comparing mean COD levels among GN divisions, Wattegedara GN division had the highest mean COD level (27.36 mgL^{-1}). This demonstrates that there is a high demand for oxygen to break down the high amount of pollutants. Dissolved Oxygen (DO) demonstrates adverse picture with 86% majority of wells having a low DO level than the standards for drinking which is less than 6 mgL^{-1}. Since there are no WHO or SLSI standards for DO, EPA, Ireland standards were used. When comparing mean DO levels among GN divisions, Wattegedara GN division had the lowest value (1.34 mgL^{-1}). This value adds more to the highly polluted well water picture of Wattegedara GN division. Biological Oxygen Demand (BOD_5) is significantly different among GN divisions ($p<0.05$). Out of all the sampled wells 36% wells had a safe BOD_5 level for drinking which had lower values than the standard (4 mgL^{-1}) according to EPA, Ireland standards. 64% had a non-safe BOD_5 level for human drinking purposes. This explains the higher organic material in the water table, which needed high oxygen amount to survive. When the parameters as BOD_5 and COD are exceeding the recommended standards that will adversely affect the biotic life. Majority of well water (88%) were not safe for drinking purposes by means of Total Coliform levels and Fecal coliform levels (85%) and non-safe TC counts and FC counts were significantly high ($p< 0.001$) in all five GN divisions. All five GN divisions recorded wells with TC and FC counts exceeding 1100 CFU/100mL where 0 CFU/100mL is the highest desirable level and 10 CFU/100mL is the maximum permissible level in drinking water for TC according to SLSI standards. FC should not be detected in 100 mL drinking water samples according to the SLSI standards. This is a serious condition since coliform bacteria are considered to be a health risk because they indicate the possibility of pathogenic microorganisms' presence[4]. The reason for this high coliform counts might be wells being polluted via surface run off contaminated with human or animal excreta and improper sewage pit constructions all over the area breaching the standard distances between sewage pits and wells. In the study area still there are small to large scale garbage dumping sites, so that there might be an effect to ground water since water table is inter-connected, and especially the study area has a very shallow water table[6]. This situation is not so wise to wait and see but requires urgent acts to prevent. To come to a solution, it's not enough to analyze the water quality parameters or water quality of each GN division separately but need a full picture of the situation in the water table of the study area. As mentioned, previous researches have done screening water quality of this study area but none of them have compared the water quality among GN divisions nor found any contamination pattern. Hence the principal component analysis (PCA) plays a significant role in this study to identify any relationships of water quality among five GN divisions. In recent years many studies have been done using principal components analysis in the interpretation of water quality parameters[27]. PCA confirmed the above findings. Results obtained from PCA analysis are shown in **Table 2** and **Fig. 3**. Eigen values greater than 1.0 were used for PCA scoring and three scores were selected (**Table 2**). First principal component (PC1) explains 44.9% of total variance of the data with 44.9% cumulative variation. And the second principal component (PC2) explains 29.9% of total variance of the data with 74.8% cumulative variation. In the scores plot of PC2 versus PC1, three clusters can be identified along PC1 axis. The groups I, II and III correspond to samples with different water quality parameters. pH, Conductivity, Total Coliform, Fecal Coliform, COD, Nitrate concentration and BOD_5 exhibited a strong relationship among them and also influence the separation of the three groups along PC1. Navinna GN division had distinctly highest conductivity (70000 μScm^{-1}) value and located separately among other clusters as ‘cluster one’. Geographically Navinna is located in the other corner away from other four GN divisions, therefore polluting sources in other GN divisions might not much be affecting Navinna water table. Moreover the reason for the high ionic condition in water may be due to previous solid waste dumping site at Navinna[7]. Since there was no proper removal of hazardous waste products dumped at the site and possibility of earlier absorbed pollutants leached into the ground water might cause this polluted situation in Navinna GN division. ‘Cluster two’ was consisted of three GN divisions Gangodawila South B, Wijerama and Jambugasmulla which showed similar pattern.

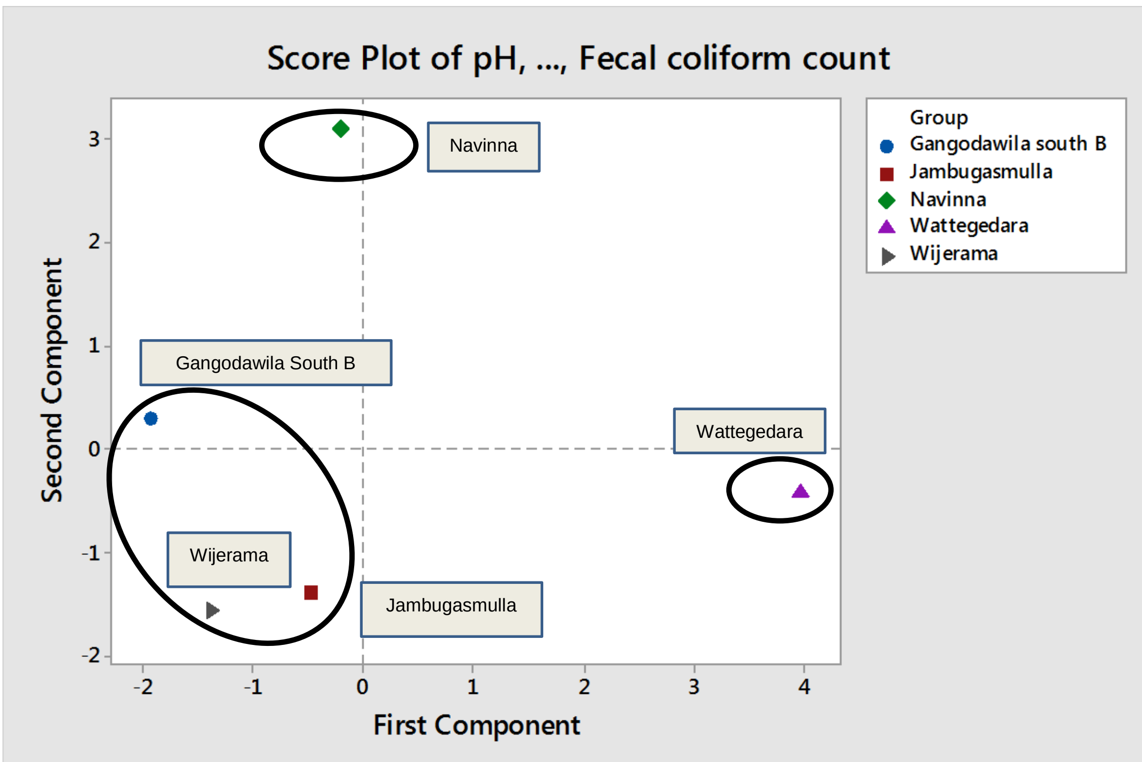

Fig. 3 Score plot of Principal Component Analysis (PCA) With Comparison of Five GN divisions in Maharagama

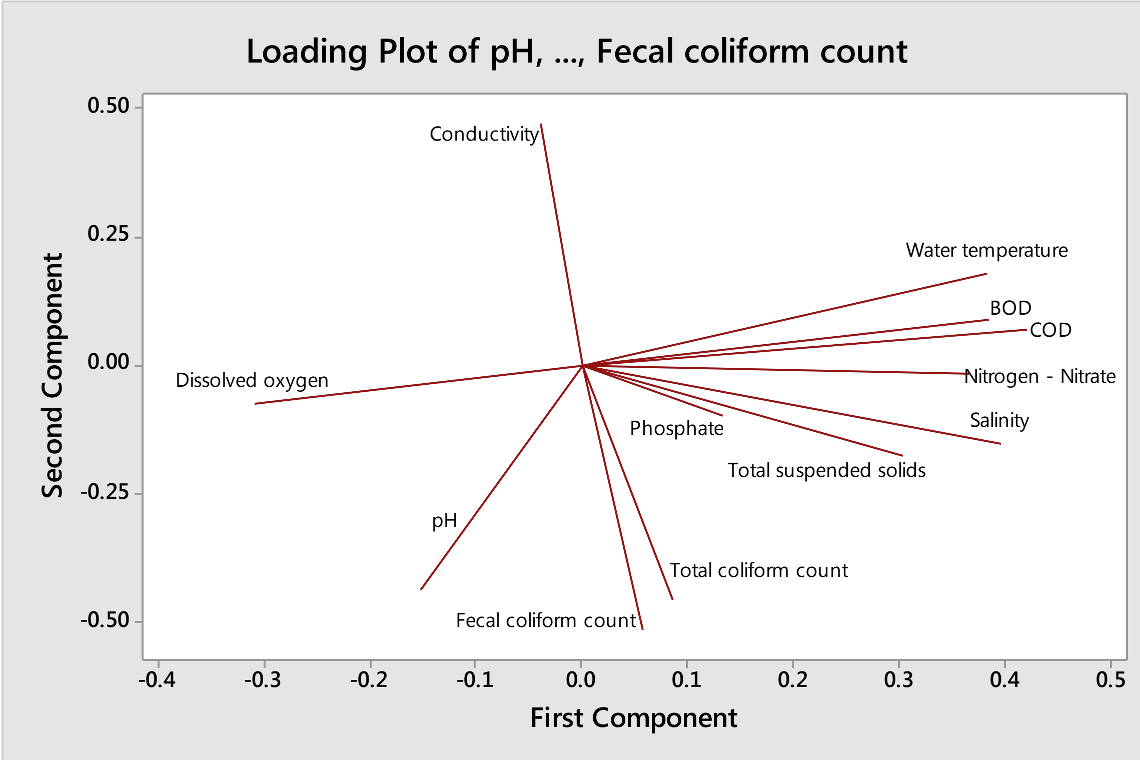

Fig. 4 Loading plot of Principal Component Analysis (PCA)

They clustered together with high alkalinity and the correlation with high total coliform and fecal coliform counts suggesting as unacceptable for drinking purposes. When considering the geographic locations Jambugasmulla, Wijerama and Gangodawila South B located near to each other (**Fig. 3**). 'Cluster three', where the site Wattegedara was characterized by high values for nitrate nitrogen, high COD, high BOD_5, Total suspended solids and salinity in all ten months study duration. PCA analysis identified three separate clusters of GN divisions which have similar microbiological and physico chemical characteristics. Therefore PCA analysis assisted to detect three new water contamination patterns in the study area. In **Fig. 3**, Wattegedara GN division (cluster 3) can be clearly identified as the most polluted well water in the GN divisions agreeing with the loading plot **(Fig. 4).** Wattegedara having the highest population out of all five GN divisions and the highest pollutant level in ground water with highest nitrate (77.3 mgL^{-1}), highest COD (27.4 mgL^{-1}) and highest salinity (0.0078 ‰) with high total coliform (412 CFU/100mL) and fecal coliform (250 CFU/100mL) indicated both chemical and microbiological pollution. According to the PCA result of **Fig. 3**, it is very clear that three GN divisions Jambugasmulla, Wijerama and Gangodawila South B (cluster 2) had almost similar water quality characteristics. This is a new finding obtained from PCA. Before conducting PCA what was only known was these three GN divisions located near to each other. Abundant home gardening with high usage of fertilizers and improper usage/planning of soakage pits and latrines are common to both cluster 3 and cluster 2. But Wattegedara GN division is situated around 'Boralesgamuwa Lake' where water quality is known to be deteriorated. However, further research is required to understand this distinguished deterioration of water quality in Wattegedara GN division compared to other GN divisions. Navinna GN division was also shown as a different cluster highlighting its high electrical conductivity value. This is the third new pattern detected from PCA analysis. This may be due to the previous solid waste dumping site of the area and probable heavy metals in the water table[7]. Therefore, it is evident that there were several well water contamination patterns throughout the study area which were identified by the PCA analysis. When suggesting a solution, knowing the overall picture is very important because shallow ground water table in the study area is inter-connected and inter-related. Therefore it will be possible to identify and conduct proper actions to prevent pollution in the clustered areas with similar water quality.

4. Conclusion

Using PCA analysis, it was possible to evaluate the well water quality of the selected five GN divisions at Maharagama identifying three different contamination patterns of water table, clustering GN divisions into three clusters based on the water quality measured by different parameters. Wattegedara was identified as the highest polluted GN division as 'cluster 3' and Jambugasmulla, Wijerama and Gangodawila South B were clustered together as 'cluster 2' with high organic pollution. Navinna GN division was the Cluster 1' with high electrical conductivity values. The results of the study showed that overall water quality of the area is deteriorated and almost all parameters tested were far above the standard given for drinking water quality by SLSI and WHO. Conducting PCA analysis shed a light to the planning of resolution process by identifying existing water contamination patterns in the study area. As the study area has a very shallow water table it is very susceptible for pollution making the situation more dangerous. Although people in the area get the water supply from National Water Supply and Drainage Board, many people in this area still use their wells for water consumption. Therefore it is essential to take appropriate actions to safe guard the human population who consumes ground water to avoid water borne illnesses.

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