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USE OF CLUSTER ANALYSIS TECHNIQUE FOR WATER QUALITY ASSESSMENT IN MAHITSY COMMUNE, CENTRAL HIGHLAND OF MADAGASCAR

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ABSTRACT

This study assessed the characteristics of well waters sampled in Mahitsy Commune using Piper trilinear diagram and cluster analysis to determine the similarities or dissimilarities among the sampling sites. The linear diagram showed that nine of fifteen water samples were of saline water type with sodium and chloride as dominant cation and anion, respectively. Five water samples were classified as bicarbonate type waters. Depending on the sampling points, calcium, magnesium or sodium was found to be the dominant cation for the bicarbonate water samples. Data clustering analysis using the hierarchical agglomerative method grouped the fifteen sampling points into three main clusters (A, B and C) based on the similarity of the water quality characteristics. The cluster groups A and B comprised nine water samples, which were of saline type and contained high concentrations of nitrate (more than 260 mg/l as NO_3^-). The cluster group C was made up of six water samples, which were all characterized by low TDS, except for one sample with a high concentration of nitrate (117 mg/l as NO_3^-).

INTRODUCTION

Groundwater is an essential component of the natural environment. Approximately, 2.5 billion people, worldwide, rely on groundwater for their basic daily water needs (WWAP, 2015). Increased pressure on the groundwater resources such as overexploitation and increased levels of pollution has deteriorated these valuable resources both in quantity and in quality for the last decades. Groundwater is susceptible to contamination, which occurs when undesirable substances from human activities get into the groundwater. Groundwater is easily contaminated, but it is difficult and expensive to clean it up afterwards (Pawari and Gawande, 2015).

Groundwater can become contaminated through natural or anthropogenic sources. Naturally occurring substances such as iron, manganese, chlorides, fluorides, sulfates or radionuclides, leached from soil or rocks reach groundwater by percolating water. Contamination can result from human-induced activities like industrial discharges, urban activities, agriculture and livestock husbandry, septic systems and waste disposals (Moody, 1996; Cherry, 1987; Waller, 1982).

Groundwater contamination could pose serious risk to human health, depending on the type of contaminant released in the water body. Use of contaminated water can cause diarrhea, respiratory problems, skin irritation, cancer and other water related diseases (Waller, 1982; Pawari and Gawande, 2015).

In rural areas of the developing countries, including Madagascar, where safe drinking water is hardly accessible, people use mainly traditional dug wells for drinking water supply. Unfortunately, there is very little information available on the chemistry of dug well water in Madagascar, enabling to assess if it is safe for drinking (Smedley, 2002).

In recent years, multivariate statistical techniques, including cluster analysis have been widely employed in water quality assessment for complex data analysis and interpretation (Huang *et al.*, 2010; Shrestha and Kazama, 2007). They are powerful tools to identify and understand factors controlling the variation of hydrochemical characteristics of water bodies (Omo-Irabor *et al.,* 2008; Shrestha and Kazama, 2007). Cluster analysis enables to classify sampling points through detecting

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similarities and dissimilarities among samples and/or variables (Singh *et al.*, 2005; Massart and Kaufman, 1983). Manoj *et al.* (2013) used Piper trilinear diagram and multivariate statistical analysis technique (cluster analysis and discriminant analysis) for characterization, classification and in-depth understanding of hydrochemistry of the ponds water in the Birbhum district of the Indian state of West Bengal. Gu *et al.* (2016) employed also cluster analysis to divide the sampling sites and months into groups according to the spatial and temporal similarities while assessing the water quality of Qiandao Lake in China.

In the present study, the purpose is to characterize the well waters in Mahitsy Commune. For that, cluster analysis is used with Piper trilinear diagram for mutual verification to determine the similarities and dissimilarities of physico-chemical characteristics between water samples.

MATERIAL AND METHOD

Study Area

The study area is located in Mahitsy Commune, in the middle part of Analamanga region, Central Highland of Madagascar (Figure 1).

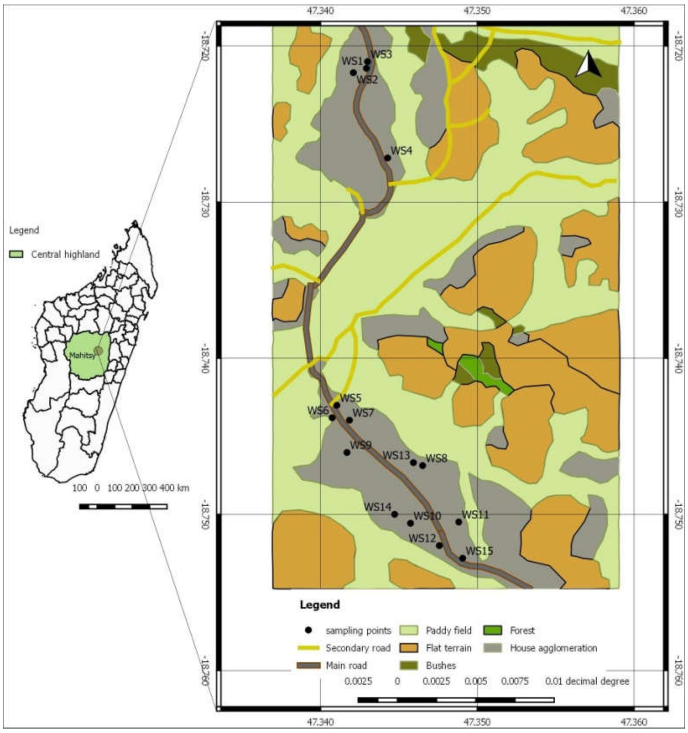

Figure 1 Location map of the study area.

The study area extends from 18˚ 43' S to 18˚ 45' S, and from 47˚ 19' E to 47˚ 23' E. The climate in the study zone is altitude tropical, characterized by warm summer (November-April) and mild winter (May-August) seasons. The mean temperature values range from 16˚ C to 24˚ C. Rainfall averages 1200 mm per year. Around 80% of the annual precipitation is available between December and March.

The region of Analamanga lies within the Central Highland plateau section, geologically characterized by crystalline rocks of Precambrian age. The crystalline basement is mainly composed of gneisses, granites and migmatites (Besairie, 1973).

The water samples are collected from traditional dug wells, tapping the upper aquifer, with water tables occurring from 2 m to 19 m below the land surface. The depth of the wells ranges from 5 m to 20 m, depending on the water point topography.

The main economic activities of the local population are predominantly farming (rice, maize, cassava and white beans) and animal husbandry (poultry and livestock). Nevertheless, farmers do not use intensively agrochemical products to yield their production. Regarding water supply, the local population mainly taps shallow groundwater from traditional dug wells for their daily water needs. With the use of traditional pit latrines as ways for sanitation for most households, the shallow groundwater is highly vulnerable to contamination. The noted improper construction and placement of those sanitation facilities could be the primary source of groundwater pollution in the area.

Sampling

Fifteen (15) water samples were collected from traditional dug wells in March 2005 and July 2005 in the Fokontany (smallest administrative delimitation in Madagascar) of Mahitsy and Antandrokomby located in the Commune of Mahitsy. The dug wells were of two types such as relatively protected well (RPW) and open-air well (OAW). The sampled wells were purged at least twice until the magnitude of pH variations did not exceed 5% prior to collecting samples in PTFE bottles. Samples were filtered using 0.2 µm membrane filters and stored in separate two bottles for anion and cation analysis. Three drops of concentrated nitric acid were added in the bottles of cation analysis sample for conservation purpose. Water parameters, including pH, total dissolved solids (TDS), and dissolved oxygen (DO) were measured in-situ using a portable multimeter. Alkalinity was also determined in the field by acidic titration with 0.16 N H_2SO_4.

METHOD

Analytical method

Cations (Na^+, K^+, NH_4^+, Mg^{++} and Ca^{++}) and anions (F^-, Cl^-, HCO_3^- and SO_4^{--}) were analyzed at the laboratory using an ionic chromatograph system (DX 120) within 0.25 mg/L as detection limit. Silica concentration was determined by spectrophotometer HACH 2010. Duplicate analysis was performed for each water sample for precision checking purpose. The precision of analytical results ranged within 5%.

Cluster analysis

Cluster analysis or clustering is a main task of exploratory mining, which aims to group a set of objects possessing similar characteristics into the same class called cluster (Shrestha and Kazama, 2007). In clustering, objects are more similar to each other within the same cluster; whereas they are dissimilar to the objects belong to other clusters. Clustering can be done using either hierarchical or non-hierarchical methods. In this study, the agglomerative hierarchical clustering technique is employed to carry out cluster analysis. It is by far the most widely used clustering method in water quality assessment (Wang *et al.,* 2013; Zhaoa *et al.,* 2012; Fan *et al.,* 2010; Hastie *et al.,* 2001). For that, it starts with each object as an individual cluster and then repeatedly merging the closest pair of clusters until all objects are in one cluster. A cluster here refers to the water points. Cluster analysis is performed on the normalized data using both Ward and average linkage methods, with squared Euclidean distance as a measure of similarity in order to check the reliability of results. The squared Euclidean distance calculation between two samples uses the analytical values of the water samples. The normalization of analytical data by standard score prior to clustering aims to increase the influence of variables of small variance and reduce the influence of those whose variance is large (Liu *et al.,* 2003). This study refers to the dendrogram, which illustrates how the clusters are merged at each step to identify the appropriate number of cluster. Cluster analysis is carried out using SPSS v.19 statistical software package.

Piper trilinear diagram

Diagram methods such as Schöeller Berkaloff, Piper diagram and Stiff diagram provide a graphical representation of water samples chemistry. In this study, Piper diagram was used to visualize the hydrochemical facies of samples. It consists of two outer triangles of cations and anions lying on a diamond baseline representing a combination of them. Water that plots at the top of the diamond is calcium sulfate waters (permanent hardness), the lower corner is sodium bicarbonate waters (alkali carbonate), the left corner is calcium bicarbonate waters (temporary hardness) and the right corner is sodium chloride waters (considered saline) (Walton, 1970). The DIAGRAMMES hydrochemical software was used to determine the water chemical facies of the water samples (Simler, 2014).

RESULTS AND DISCUSSION

Water quality description

The water quality assessment included the measurement of major ions (cation and anion), nitrate, ammonium, total dissolved solids (TDS), dissolved oxygen (DO) and pH. Physical characteristic of water samples such as temperature was also determined. Table 1 details the descriptive statistics of the physico-chemical parameters for all water samples, which are considered part of this study.

Water temperature ranged from 20.9 to 24.6 °C with a mean concentration of 21.9 °C. pH and TDS varied in the ranges of 3.9-6.4 and 6.7-868 mg/l, averaging 5.0 and 390 mg/L, respectively. The shallow groundwater in the area of study fell under fresh water category, as TDS concentration was below 1000 mg/l (Freeze and Cherry, 1979). The range and the mean concentration of DO were 1.0-8.4 mg/l and 3.8 mg/l, respectively. The sampled dug wells tapped water from oxic groundwater (DO greater than or equal to 0.5 mg/l). As for cations, the sodium and potassium concentrations lay in the range of 3.5-150.5 mg/l and 3.4-175 mg/l with mean values of 67.6 mg/l and 47.2 mg/l, respectively. Chloride and nitrate were measured in higher concentrations in some water samples, ranging from 0.2-205 mg/l and 1.4-580 mg/l, respectively. Eleven out of fifteen water samples had nitrate concentration exceeding the WHO recommended value (50 mg/l as nitrate) for drinking water (WHO, 2017). The presence of nitrate in higher concentration in the shallow groundwater of Mahitsy could be due to infiltration from pit latrines located around the water points (Rasolofonirina *et al.,* 2015).

Table 1 Water quality data in the study area.

Water Point	Na^+ *[mg/l]*	K^+ *[mg/l]*	Mg^{2+} *[mg/l]*	Ca^{2+} *[mg/l]*	Cl^- *[mg/l]*	NO_3^- *[mg/l]*	SO_4^{2-} *[mg/l]*	HCO_3^- *[mg/l]*	NH_4^+ *[mg/l]*	Silica *[mg/l]*	pH	TDS *[mg/l]*	T *[°C]*	DO *[mg/l]*
WS1	18.0	19.9	15.1	3.1	20.3	117	0.7	8.2	0.0	11.6	4.67	307	21.1	2.04
WS2	8.1	6.4	9.6	1.8	2.1	23.6	0.3	51.2	0.0	12.7	5.53	77.6	20.9	2.64
WS3	21.2	7.0	4.2	1.3	2.1	80.7	0.3	10.6	0.0	11.7	5.24	92	20.9	4.27
WS4	3.5	3.8	1.6	0.8	1.4	16.9	0.6	6.6	0.0	7.0	5.24	23.6	21.5	16.28
WS5	109	121	17.6	45.0	141	340	15.0	41.5	0.0	5.6	5.42	644	23.4	6.53
WS6	94.9	31.5	13.3	33.2	79.7	264	2.6	31.4	0.0	7.7	6.00	421	21.7	8.35
WS7	151	175	31.4	33.9	205	538	8.7	15.1	0.0	5.3	5.37	850	22.2	2.00
WS8	142	110	24.8	34.8	168	580	3.4	21.7	18.4	10.0	3.93	868	21.4	1.00
WS9	98.9	46.0	21.5	32.8	103	365	6.3	9.4	0.0	8.0	4.88	508	21.1	2.00
WS10	61.5	34.5	9.2	25.3	57.7	345	1.6	6.2	20.5	4.3	4.45	424	24.6	1.00
WS11	107	60.9	11.5	32.3	151	343	1.1	5.9	10.4	4.8	4.33	612	22.4	1.00
WS12	4.6	5.5	1.4	13.4	6.3	15.6	1.2	46.7	0.0	17.5	6.38	58.9	23.6	5.80
WS13	85.7	38.0	16.8	24.5	88.5	325	0.3	1.2	0.0	12.3	4.56	424	21.0	5.80
WS14	105	44.8	19.1	27.5	74.5	460	0.3	0.0	0.0	7.9	4.14	533	21.0	2.31
WS15	4.6	3.4	0.8	1.3	0.2	1.4	0.3	24.4	0.0	6.8	4.58	6.7	21.8	6.36

Table 2 Correlation matrix of water chemistry

	pH	TDS	DO	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-
pH	1	-0.397	0.588*	-0.327	-0.298	-0.266	-0.089	-0.608*	-0.241	-0.511	0.202	0.724**
TDS		1	-0.580*	0.971**	0.985**	0.870**	0.895**	0.423	0.945**	0.935**	0.613*	-0.229
DO			1	-0.494	-0.524*	-0.438	-0.350	-0.693**	-0.512	-0.682**	-0.232	0.334
Na^+				1	0.968**	0.857**	0.904**	0.319	0.929**	0.893**	0.593*	-0.154
K^+					1	0.875**	0.900**	0.324	0.957**	0.900**	0.655**	-0.204
Mg^{2+}						1	0.789**	0.066	0.846**	0.871**	0.524*	-0.186
Ca^{2+}							1	0.296	0.918**	0.793**	0.800**	0.082
NH_4^+								1	0.352	0.465	0.244	-0.263
Cl^-									1	0.850**	0.695**	-0.136
NO_3^-										1	0.527*	-0.379
SO_4^{2-}											1	0.280
HCO_3^-												1

**Correlation is significant at the 0.05 level (2-tailed).*
*** Correlation is significant at the 0.01 level (2-tailed)*

Table 2 indicated significant correlations between TDS and dissolved oxygen ($r = -0.580$) at $p < 0.05$ level. This revealed that water samples with low dissolved oxygen concentration registered high concentration of TDS. The correlation matrix (Table 2) depicted also that there were strong and significant correlations between chloride - sodium ($r = 0.929$), chloride - potassium ($r = 0.957$) and chloride - calcium ($r = 0.918$) at $p < 0.01$ level. Similarly, strong and significant correlations were recorded between nitrate - sodium ($r = 0.893$) and nitrate - potassium ($r = 0.900$) at $p < 0.01$ level. This suggested that the occurrence of chloride and nitrate in the shallow groundwater of the study area could be associated with that of sodium and potassium.

Hydrochemical facies

The Piper diagram (Figure 2) revealed that alkali metals (Na^+ and K^+) exceeded alkaline earths (Ca^{2+} and Mg^{2+}), whereas strong acidic anions (Cl^- and SO_4^{2-}) exceeded weak acidic anion (CO_3^{2-} and HCO_3^-). A majority of water samples (60%) fell in the right corner of the Piper diamond, representing water of saline category. Table 3 details the hydrochemical facies of sampled waters. Five of the fifteen samples were bicarbonate type waters with mixed cation predominance for two of them.

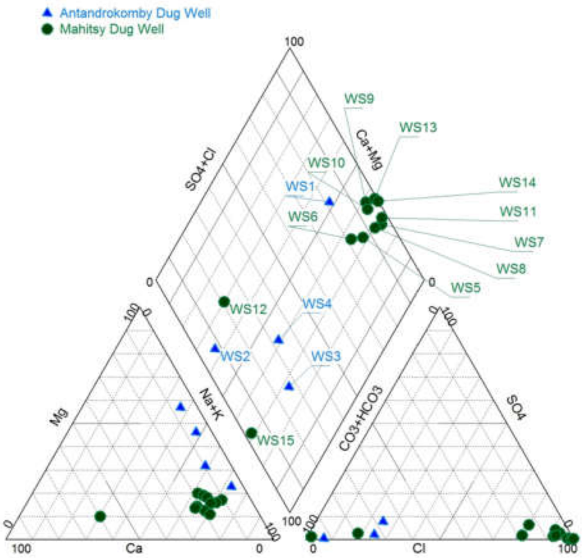

Figure 2 Piper diagram showing the hydrochemical facies of water samples.

Table 3 Hydrochemical facies of water samples.

Category number	Water point	Type of water
Category 1	WS6, WS11, WS13, WS14	Na - Cl
Category 2	WS5, WS7, WS8	Na - K - Cl (mixed)
Category 3	WS9, WS10	Na - Ca - Cl (mixed)
Category 4	WS2	Mg - HCO_3
Category 5	WS12	Ca - HCO_3
Category 6	WS3	Na - HCO_3
Category 7	WS4	Na - Mg - HCO_3 (mixed)
Category 8	WS1	Mg - Na - Cl (mixed)
Category 9	WS15	Na - K - HCO_3 (mixed)

Data clustering

This study used the water constituents provided in Table 4 for the hierarchical agglomerative cluster analysis. pH and TDS were not considered in data clustering to enable comparison to be made with the results of the Piper trilinear diagram.

Table 4 Water constituents used for the hierarchical agglomerative cluster analysis.

Parameter	Unit
Na^+	mg/l
K^+	mg/l
Ca^{2+}	mg/l
Mg^{2+}	mg/l
Cl^-	mg/l
SO_4^{2-}	mg/l
HCO_3^-	mg/l

The water constituent values were first log-transformed prior to data standardization in order to balance the differences between the variance of the variables. The squared Euclidian distance is highly sensitive to variables with a large dispersion. This study employed a z-score method for data standardization. Log transformation combined with data standardization (conversion to z-scores) gives water constituents equal weights while performing data clustering (Ryberg, 2006).

Figure 3 depicts the dendrogram resulting from the hierarchical agglomerative cluster analysis of the water quality dataset using Ward method, as a measure of proximity. The fifteen (15) water samples were clustered into three (3) major groups, labeled as A, B and C, since the linkage distance between them was relatively large, indicating that the water samples were quite dissimilar between inter cluster groups.

The cluster group A contained water samples from WS5, WS6, WS7, WS8, WS9, WS10 and WS11 water points, whereas the cluster group B consisted of water samples from WS13 and WS14. The cluster group C included six water samples collected from WS1, WS2, WS3, WS4, WS12 and WS15 water points.

Six subgroups could be identified within the three major clusters through dendrogram examination, as shown in Figure. One (1), two (2) and three (3) subgroups fell within the major cluster B, A and C, respectively. Subgroups 1, 2 and 3 contained water samples within which chloride and sodium were dominant anion and cation, respectively. The sub clustering into three (3) subgroups resulted from the relative amount of chloride and sodium in the water samples. In subgroup 3, water samples from WS13 and WS14 contained more than 99% Cl^- and over 50% Na^+. The relative amounts of K^+, Ca^{2+} and Mg^{2+} are about 13%, 18% and 16%, respectively. In subgroup 2 (WS5, WS7 and WS8), Cl^- and Na^+ were considered to be the dominant ions, but in less extent compared to those in subgroup 3. The relative amount of Cl^- ranged from 80% to 93%, whereas that of Na^+ varied between 41% and 48%. As far as subgroup 1 (WS6, WS9, WS10 and WS11) was concerned, the relative amount of Cl^- and Na^+ varied in the same magnitude of that of subgroup 2. The difference lay in the gradual increase of the relative amount of Ca^{2+} in the water samples included in the subgroup 1.

The cluster group C included the water samples of low TDS, except for sample from WS1 water point, which contained a high concentration of nitrate. They were different from water samples in cluster groups A and B regarding hydrochemical facies. In subgroup 4, the water samples from WS2 and WS3 were firstly merged as they had the same dominant anion (HCO_3^-) of relative amount in range of 72% and 93%.

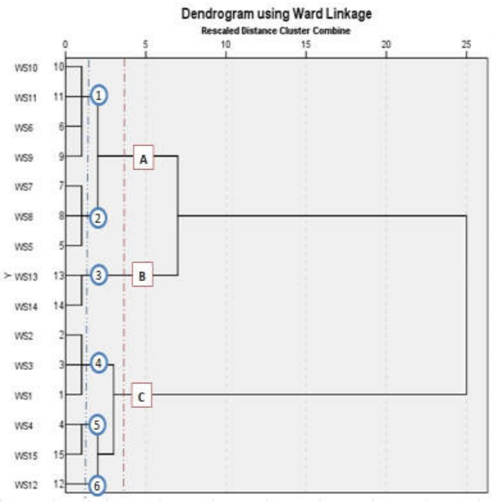

Figure 3 Water samples Dendrogram using Ward linkage method.

The water sample from WS1 joined the subgroup 4 afterwards, since it presented a similar relative amount of Mg^{2+} with the water sample from WS2. As for the subgroup 5, the common characteristic of water samples from WS4 and WS15 is that they had the same dominant cation (Na^{+}) and anion (HCO_3^{-}). The relative amount of sodium and bicarbonate ranged from 36% - 48% and 67% - 97%, respectively.

Figure 4 displays the dendrogram of the water quality dataset after performing cluster analysis applying the average linkage method, as a measure of similarity. The same water parameters were log-transformed and standardized through z-score method, as done for the Ward linkage method. The cluster groups that were produced were very similar than those produced when the Ward linkage method was used as a measure of proximity in the hierarchical cluster analysis.

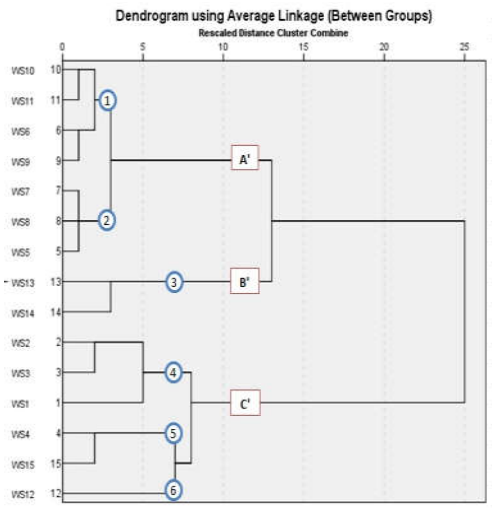

Figure 4 Water samples Dendrogram using average linkage method.

There were six (6) different sub-clusters distributed in three (3) cluster groups. The cluster group A' contained the water samples from WS5, WS6, WS7, WS8, WS9, WS10 and WS11 sampling points, whereas the cluster group B' included the water samples from WS13 and WS 14 sampling stations. As for the cluster group C', it was made up of the water samples from WS1, WS2, WS3, WS4, WS12 and WS15 water points. The difference between the two methods was found in the distance between the clusters at the time of merging. There was a large jump in the distance between clusters with the average linkage method compared to that with the use of the Ward linkage method. It suggests that the clusters produced in the Ward method were relatively close together when they were merged, whereas they were relatively far apart with the average linkage method when they were joined.

CONCLUSIONS

This study depicted the occurrence of high nitrate concentration in the water samples. Eleven of fifteen presented a nitrate concentration exceeding the WHO recommended value (50 mg/l as NO_3^{-}).

In this study, Piper trilinear diagram and cluster analysis were used jointly to explore the water quality characteristics. Nine of fifteen samples were classified into the saline water category with sodium and chloride as dominant cation and anion, respectively. Five of fifteen samples were classified as bicarbonate type waters with the cation dominance of calcium, magnesium or sodium, depending on the case. The water samples in the saline category had similar ionic composition with respect to each other, suggesting that similar geochemical processes may control major ion composition in those samples. The hierarchical agglomerative cluster analysis classified the sampling points into three cluster groups (A, B and C) based on similarities in water quality features. The samples in the cluster groups A and B were found in the saline water category with highest nitrate pollution level, whilst the samples in the cluster group C were characterized by low TDS, except for sample from WS1 sampling point, which had a high concentration of nitrate. The obtained results revealed the importance and usefulness of data clustering method when exploring water quality dataset for categorizing data purpose.

The use of Ward linkage method as a measure of proximity in data clustering was more appropriate for grouping sampling points in water quality assessment. The water samples dendrogram using Ward linkage method revealed a small jump in the distance between clusters compared to that with the use of the average linkage method, when clusters were merged.

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