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Scientific Research

Assessment of Groundwater Quality Monitoring Network Using Cluster Analysis, Shib-Kuh Plain, Shur Watershed, Iran

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Abstract

In addition to failure in monitoring water quality in the study area, the monitoring networks are not designed based on standard guidelines; moreover, there is no ongoing assessment of these networks. The great or small number of sites in the monitoring networks will cause problems. This paper aims to evaluate the monitoring networks of the changes in groundwater quality of the Shib-Kuh aquifer established in 2005 in South West of Iran. The aim of this study is to improve the monitoring networks and save expenses. In this aquifer, the groundwater main chemical anions, cations, EC, TDS, TH, SAR and pH are measured in 20 sites. The statistical cluster analysis methods are used and observations, variables and sampling sites are analyzed and evaluated. The results showed the probability of about 25 percent reduction in the sites. It also proved that it was possible for some of the measuring parameters to have been removed. Cluster analysis method is a suitable way to evaluate the quality of establishment as well as the function of the monitoring networks of water resources. Through the application of this method, the number of sites, variables, or both of these factors can be optimized and this optimization leads to upgrading of monitoring networks.

Keywords

Groundwater, Monitoring, Cluster Analysis, Iran

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1. Introduction

The regional monitoring network that was created to record changes in groundwater quality was often incomplete and therefore it was difficult to identify and interpret the results and analysis of the process of changes [1]. The groundwater monitoring is a tool for evaluating environmental and agricultural policies [2]. Groundwater quality monitoring is quite necessary, but often the number of sites in the monitoring networks is a challenging problem. Through the application of geo-statistical and water quality monitoring, came up with the conclusion that there is an insufficient number of monitoring sites as well as the lack of monitoring network coverage in areas with high vulnerability [3]. The province water companies affiliated to the Ministry of Energy are responsible for groundwater aquifer studies in Iran. They usually record monthly fluctuations of the level of groundwater tables in the observation wells and measure electrical conductivity (EC) and chloride (Cl^-) in a number of selected wells. Results are usually reported and published in the form of monthly periodicals. These are the main methods for monitoring the quantity and quality of groundwater resources of the country. The other set of information about the aquifer groundwater is provided through the short term monitoring undertaken within the framework of the post graduate studies. A short-term monitoring of groundwater salinity in artificial recharge system in Gareh-Bygone showed a reduction in the Salinity [4]. The artificial recharge with floodwater spreading proved to have positive effects on the groundwater quantity and soil properties [5].

The current status of the country indicates that the groundwater quality monitoring networks are primarily not designed based on standard guidelines, and there is no ongoing assessment and evaluation of their performance. They are often presented in the form of data collection which most of the times contain deficiencies. Therefore, evaluation of monitoring networks seems to be necessary. It seems that the first step in this process is to evaluate the networks in terms of the number and location of the measurement sites as well as the number of the chemical factors and observations. Cluster analysis was used to investigate the time-series hydrochemistry of groundwater and adopted cluster analysis to evaluate the monitoring networks [6]. The object of this work is to highlight the importance of water quality monitoring in the country, clarifying the possible shortcomings of existing networks, reforming and ultimately reducing expenses in this field. To achieve this goal, a part of the Shib-Kuh plain in the South West of Iran was selected. In this area, a monitoring project was established to measure the changes of 12 chemical factors in groundwater from 2005 to 2012.

2. Methodology

2.1. Description of the Study Area

The groundwater time series data were collected from 20 sites (wells) in the southern part of Shib-Kuh aquifer called Gareh-Bygone. Gareh-Bygone area is 82.76 km^2 and located 50 km South East of Fasa in Fars province between the northern latitudes 28˚35' to 28˚41' and eastern lengths 53˚53' to 53˚ in South West Iran (**Figure 1**). The climate of the area under study is semiarid with an average annual rainfall of 255 mm, an average annual air temperature of 20˚C, and an average annual potential evaporation of 2860 mm. The aquifer type is unconfined alluvial, which consists of carbonates and silica particles with gravel, silt and clay types [7] [8]. Geological outcrops in the watershed and adjacent plain are Eocene-Pleistocene sedimentary rocks. The aquifer bedrock consists of fine siltstone and mudstone. This fine material has a little hydraulic conductivity of about 2×10^{-4} meters per day [9]. Groundwater table depth is between 10 to 40 meters below the ground surface in different points. Saturated section of aquifer thickness changes from less than one meter to more than 12 meters. Pumping wells are often wide span and rate of groundwater extraction is 5 to 20 LS^{-1} and its average of 8 LS^{-1}.

2.2. Sampling and Measurements

20 wells out of a total of 100 wells used for agricultural exploitation were selected (named W1 to W20, see **Figure 1**), and water sampling and chemical analysis were conducted on the wells. Using standard water analysis laboratory methods, major ions and general factors were measured including calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), chloride (Cl^-), sulfate (SO_4^{2-}), bicarbonate (HCO_3^-),and electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), pH and sodium absorption ratio (SAR).

2.3. Initial Review of the Data

Time series generated from 450 samples of groundwater from 20 sites between the time periods 2005 to 2012

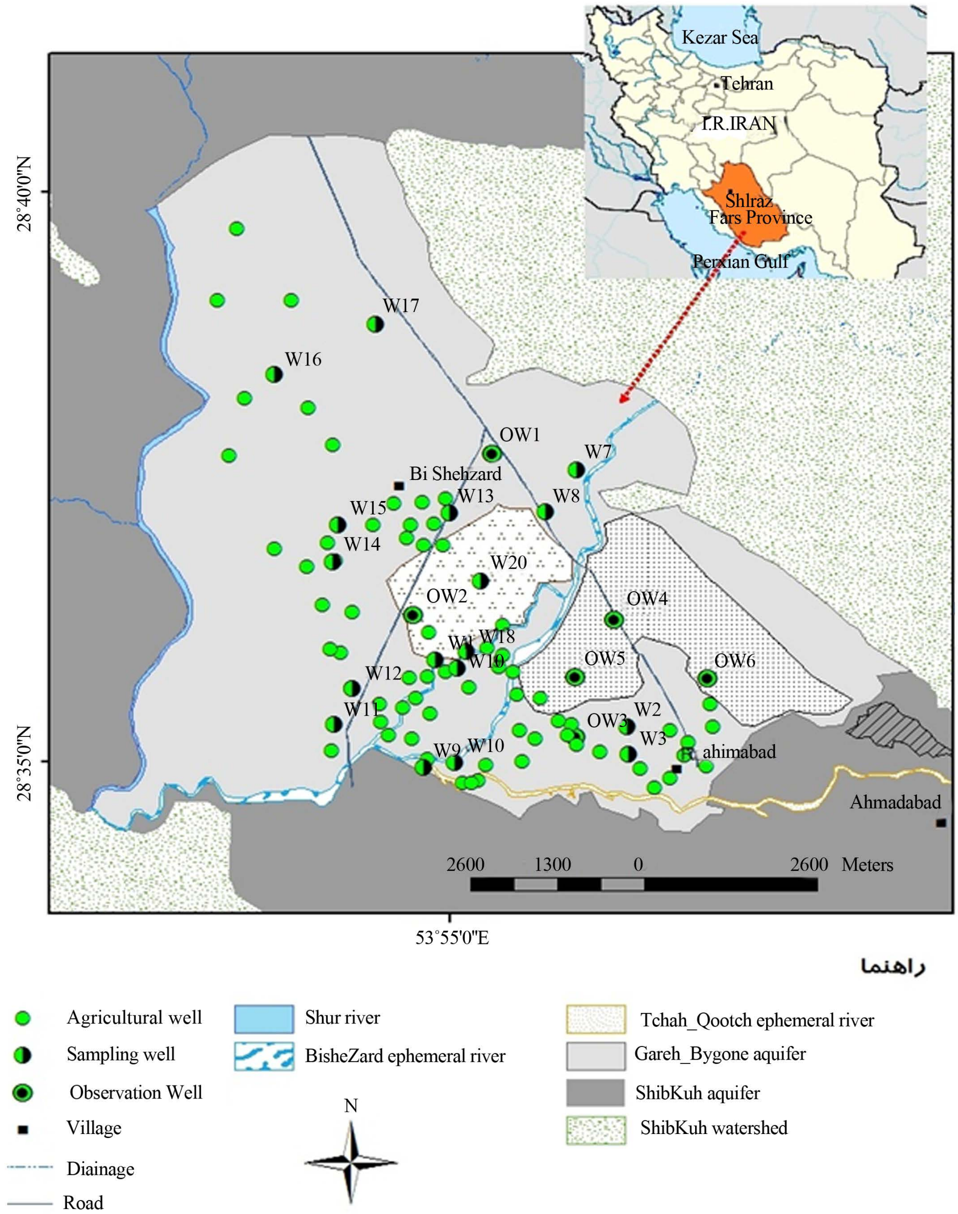

Figure 1. Area under study: Gareh-Bygone aquifer, South of Shib-Kuh plain, Fars Province, SW of Iran.

were prepared, reviewed and inputted to MINITAB 14. The factors were measured in different units and accordingly the data were standardized via statistical tests. Multivariate cluster analysis was used to determine the similarity between the sites as far as important chemical factors were concerned. The researchers in the present study considered both electrical conductivity (EC) and total dissolved salts (TDS) as the most important factors [10]-[13]. As a result, long series of electrical conductivity (EC) and total dissolved salts (TDS) were also extracted and analyzed through cluster analysis.

2.4. Cluster Analysis

In cases where the number of variables, observations, measurements or sites is large for the analysis, multivariate statistical analysis methods are used. The methods are utilized for data reduction and better understanding of the relationships between and among the variables and observations. One of these methods which is usually used for grouping data is *cluster analysis*. Cluster analysis helps cluster and group the data in three forms: observation clustering, variable clustering, and K-means clustering. All these analyses are conducted through statistical software. In the clustering the data certain factors are important: the final number of groups based on which the data may be clustered, the nature of data, data type, data sensitivity, and the role of the researcher. Finally, a dendrogram is generated to present cluster analysis that can help researchers determine the final number of groups. First, without specifying the final group number, the software will conduct the grouping process, yielding a dendrogram. Then, with respect to the similarity percentage or the distance between the groups considered by researcher, a dendrogram of final transect groups is generated. Then, the final number is entered and the software will process the re-grouping of the data. In this study, cluster analysis was conducted in Minitab 14, and observations, variables, and groups of the sampled sites were compared and interpreted.

3. Results and Discussion

Cluster analysis of 20 monitoring sites based on the values of 12 chemical factors identified two or multiple member clusters of sites in which groundwater quality and its changes show over than 96% - 98% similarity. Accordingly, 20 site clusters were put into 9 logical clusters: two-member included (a) W2 and W9; (b) W17 and W12; five-member included (c) W5, W11, W14, W15 and W16; and five-member included (d) W1, W19, W18, W7, W20 and W8;. Some sites such as W3 and W13 were found to be less similar and were separated from the other sites (**Figure 2(a)**). Analysis of similarities due to the main general chemical factors of EC and TDS of 20 monitoring wells revealed that they could be divided into 4 clusters. Here the groups containing two or more members exhibited over than 90% similarity (**Figure 2(b)**). Cluster analysis, according to the Cl^-/HCO_3^- and Mg^{2+}/Ca^{2+} ratios and $Na^+ + K^+$ and $Ca^{2+} + Mg^{2+}$, (**Figure 2(c)**) and according to the values of EC, TDS, TH, pH, Na^++K^+ and Cl^-/HCO_3^- ratios, (**Figure 2(d)**), also demonstrated relatively same results.

Results show that some of the sites could be eliminated while maintaining the accuracy of the monitoring program in this project. Due to the similarity within groups and clusters, the number of sites can be adjusted step by step until the desired accuracy is achieved. Here, more than 25% of the sites can be eliminated. This makes it possible for managers to develop new sites or expand existing sites tested parameters.

The seasonal values cluster analysis, according to the seasonal values of major ions, indicated that the variables could be clustered into 2 groups. Clusters with two or more members also showed 92% to more than 99% similarity. The variables were thus clustered: (a) $Na^+ + K^+$ and, Cl^-, SO_4^{2-} and Mg^{2+}; (b) Ca and HCO_3^- (**Figure 3(a)**). The clustering according to the seasonal values of EC, TDS and pH, indicated that the EC and TDS could be clustered into one group with over than 85% similarity and pH showed about 53% similarities and were thus separated from others (**Figure 3(b)**).

From a seasonal perspective, observations of spring and winter showed about 70% similarity and observations of autumn represented the lowest degree of similarities due to the EC, TDS and pH values (**Figure 3(c)**), but according to the major ions, spring observations represented the lowest degree of similarities (**Figure 3(d)**).

Cluster analysis based on years of observations shows that the first year (2005) was least similar to other years and for this reason it was separated. Years 2006 and 2007, and 2008 with 2010 and 2011 with 2012 shows over than 99% similarity (**Figure 4(c)**). These high similarities could be demonstrated the similar condition in the aquifer from point of water extraction or recharge in period of our studies. The cluster analysis of annual values of chemical factors in the aquifer revealed that many clusters containing two or more members of variables could be formed with about 85% - 100% similarity (**Figure 4(a)** and **Figure 4(b)**).

The seasonal or annual clustering results of variables and observations represent a tool to manage the variables measured during the monitoring period while it can help the management process and improve the number of sites.

Cluster analysis of annual values of TDS, EC, TH, pH and SAR in 20 wells, revealed that many clusters containing two or more members of variables could be formed with about 15% - 100% similarities. TDS, EC created a cluster with about 100% similarity and can also cover TH although with a minor similarity reduction. SAR and pH as separate cluster showed the least similarity to the others (**Figure 5(a)**). The 3-member groups of SO_4^{2-}, Ca^{2+}, and Mg^{2+}, showed about 97% internal similarity. This group showed about 95% similarity with Cl^-, and formed a 4-member cluster. The 2-member groups of HCO_3^- and Na^+, showed about 97% internal similarity and K^+ as separate cluster showed the least similarity to the others (**Figure 5(b)**). Cluster analysis of annual values of 12 chemical factors in 20 wells, showed five clusters about 12% - 100% similarity. The major cluster

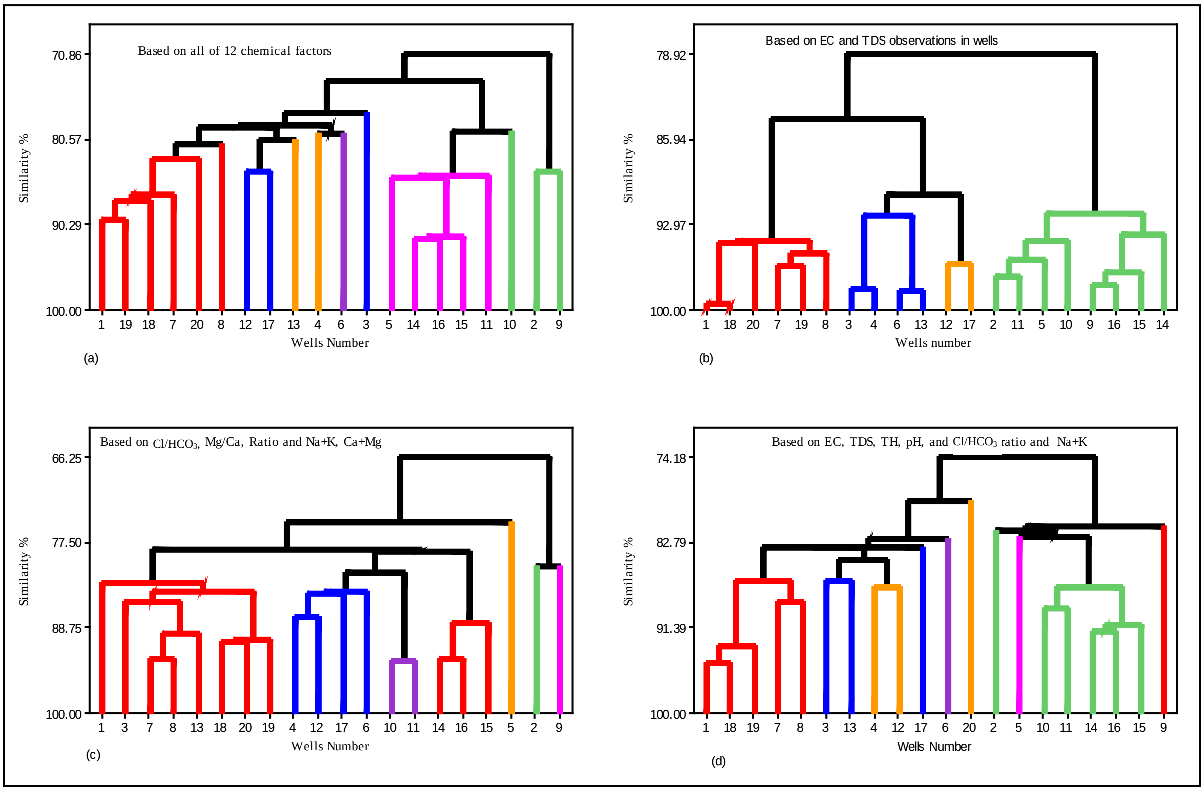

Figure 2. Dendrogram of the monitoring wells clustering (1: W1, 2:W2 …).

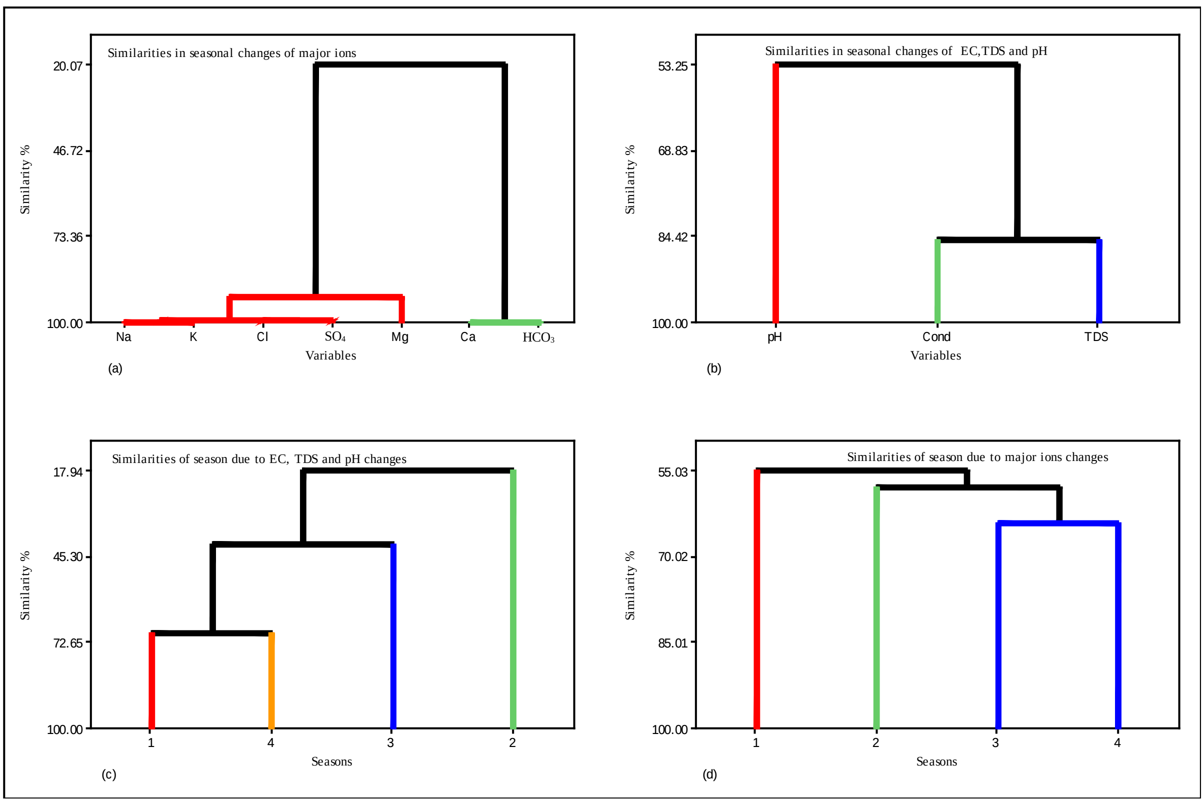

Figure 3. Dendrogram of the seasonal observations and seasons clustering (1: Spring, 2: Summer …).

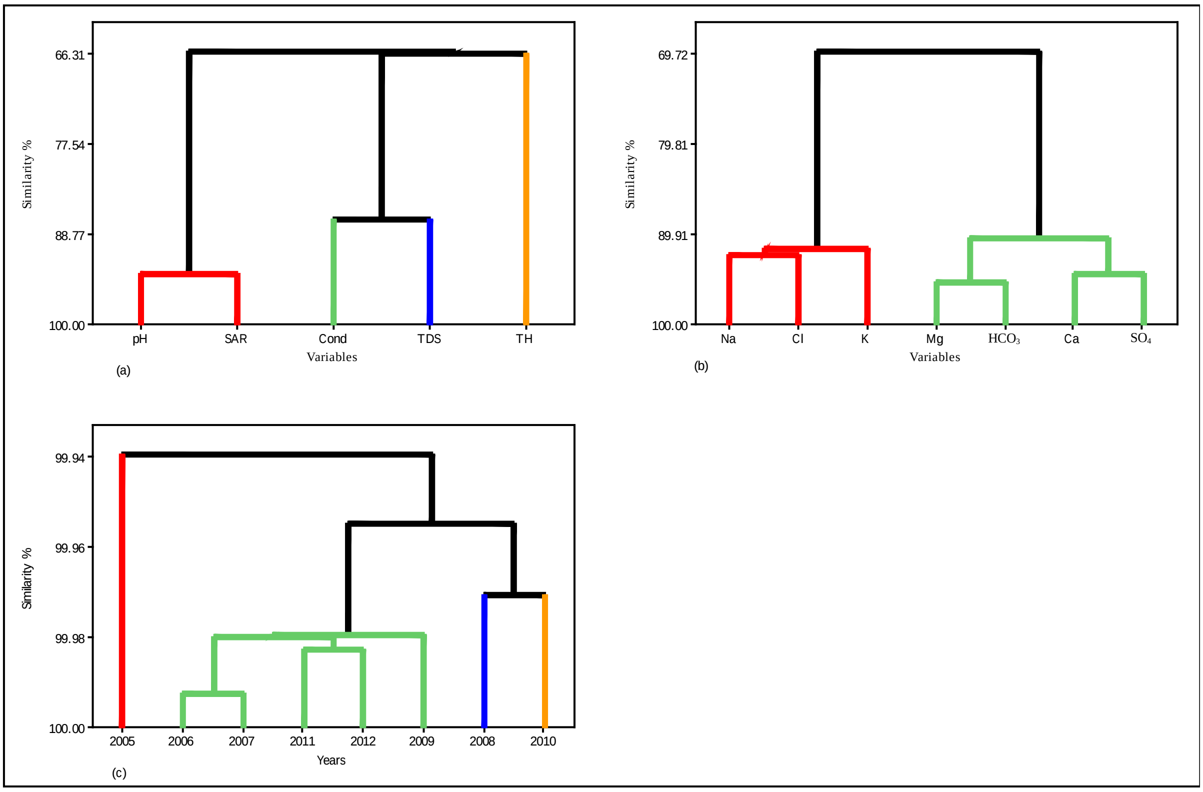

Figure 4. Dendrogram of the annual mean of groundwater chemical variables and years observations clustering.

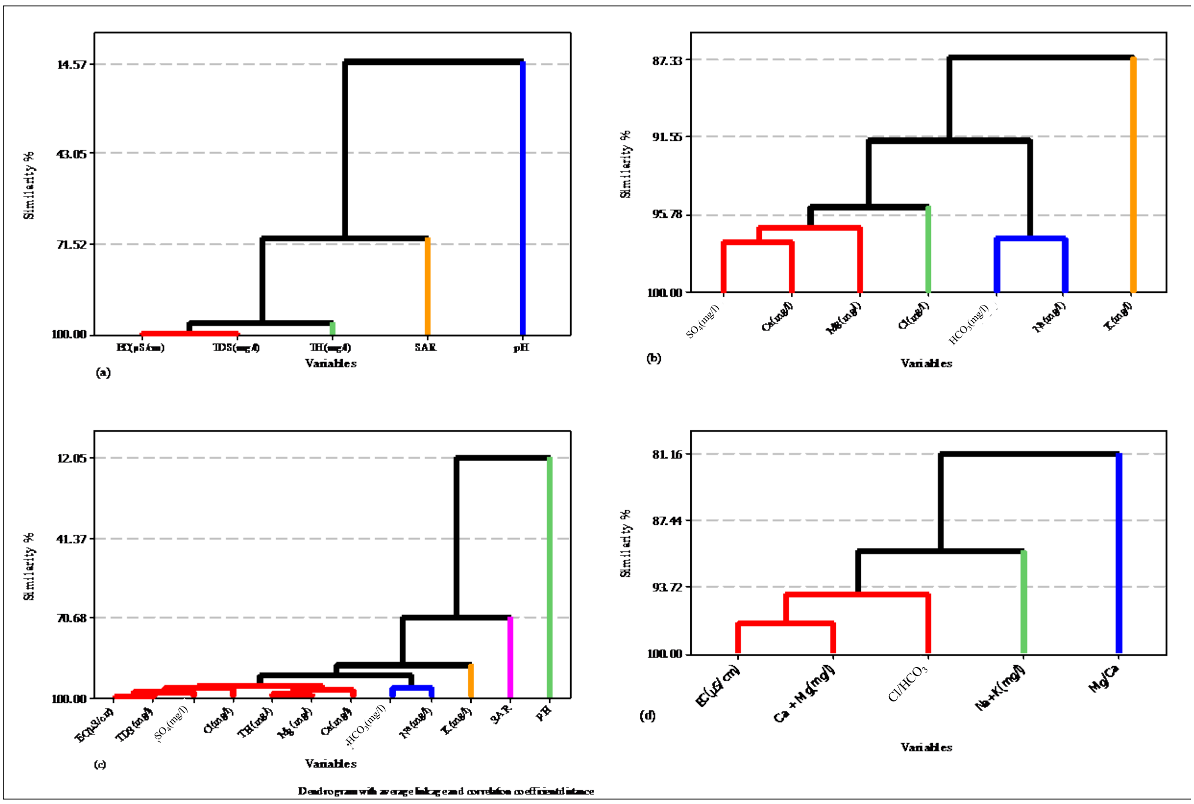

Figure 5. Dendrogram of clustering of the groundwater chemical variables.

with 7 members, included TDS, EC, TH, SO_4^{2-}, Ca^{2+}, and Mg^{2+}, with about 100% similarities. In this analysis as also pH is separate cluster and showed the least similarity to the other variables (**Figure 5(c)**). The clustering according to the many ions ratio and ions summation and general or main chemical factors such as EC, shows 80% - 97% similarities between variables (**Figure 5(d)**). In this analysis Cl^-/HCO_3^- ratio, match to the EC higher than Mg^{2+}/Ca^{2+} ratio and $Ca^{2+} + Mg^{2+}$ value as match to the EC higher than $Na^+ + K^+$ value.

4. Conclusion

Statistical cluster analysis is an optimal method to assess the establishment and operation of groundwater quality monitoring network. Using this method to extract the similarity between and among monitored sites or measured variables can optimize the number of sites and/or variables, reduce costs, and improve the monitoring strategy. Decreasing 25% of the sites or even eliminating some of the measured parameters in this study, emphasizes the necessity to evaluate the groundwater monitoring network and its significant impact on the assessment and management of water resources.

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