Spatio-seasonal Analysis of Unconfined Groundwater Quality Using Self-organizing maps in the Red River Delta, Vietnam

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1. Introduction

The Red River Delta (RRD) is the second largest delta and one of the most densely populated regions in Vietnam. In the RRD, all its residents depend entirely on groundwater for their domestic water supply. Identification of hydrogeochemical characteristics can help further understand the geochemical processes, hydrodynamics and origin of groundwater, as well as its interaction with the aquifer materials (Furi et al., 2011). However, there has been little available information regarding hydrogeochemical characteristics of the groundwater in the RRD on the basis of major ion chemistry, especially the seasonal properties of hydrogeochemitry.

Groundwater interacts with surface hydrologic systems, such as rivers, lakes, and oceans, and is indirectly influenced by seasonal changes during recharge and discharge. Thus, the change in seasons can potentially affect the hydrogeochemical properties of groundwater, especially in areas that have two distinct dry and rainy seasons, like Vietnam. Investigation of seasonal changes in the hydrogeochemical properties may help improve the data collection programs for groundwater assessment and enable better use of groundwater supplies. In addition, in the RRD, the groundwater mostly exists as porous water that forms the topmost Holocence unconfined aquifer and the Pleistocene confined aquifer, with the former having a high probability to be contaminated by pollutants from domestic as well as agricultural and industrial sources. Therefore, hydrogeochemical studies of the unconfined groundwater in the RRD will provide a better understanding of possible changes in quality and thus, help in mitigating the inferior quality as well as effectively managing the groundwater resources.

Recently, the self-organizing maps (SOM), an unsupervised Artificial Neural Network, has been widely used as a powerful and effective data analysis tool in the exploration of data properties in many research fields (Jin et al., 2011). However, SOM utilize in classification of groundwater hydrogeochemitry is rare. This study attempted to apply SOM for investigation of the seasonal and spatial hydrogeochemical characteristic of the unconfined aquifer groundwater in the RRD, Vietnam.

2. Study area and data used

The RRD is second largest delta in Vietnam with a total area of about 13,000 km^2. The population was about 20 million in 2012, occupying 23% of the Vietnam's population. The RRD belongs to the tropical monsoonal region with two distinctive seasons. The rainy season is from May to October and the dry season lasts from November till April. The annual rainfall is about 1,600 mm of which rainfall in the rainy season occupies about 75%. The river network is quite dense with the density of about 0.7 km/km^2 (Bui et al. 2012).

Groundwater samples were collected from 47 observation wells in the dry and rainy seasons in 2011 to investigate the hydrogeochemical characteristics of unconfined groundwater in the RRD. The hydrogeochemical data used in this study consist of major dissolved ions (Cations: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}; Anions: HCO_3^{-}, Cl^{-}, SO_4^{2-} and CO_3^{2-}). Standardization of the data is necessary prior to the application of SOM to ensure that all values of the chemical parameters are given the same or similar importance. In this study, the range of the standardized values of the hydrogeochemical data, for all parameters, is 0 to 1.

3. Methodology

The SOM, developed by Kohonen (2001), can project high-dimensional, complex target data onto a two-dimensional regularly arranged map in proportion to the degree of properties (Jin et al. 2011). In general, the objective of the SOM application is to obtain useful and informative reference vectors. These vectors can be acquired after iterative updates through the training of the SOM. Design of the SOM structure, selection of a proper initialization method, and data transformation methods were carried out in the SOM application process. The reference vectors obtained from the SOM application were fine-tuned using cluster analysis methods. The optimal number of clusters was selected by the Davies-Bouldin index (DBI) using the k-means algorithm. Using the optimal number of cluster, a final fine-tuning cluster analysis was carried out by Ward's method.

4. Results and discussion

Fig.1 shows that the groundwater chemistry data was classified into five clusters. In order to numerically characterize the classified data, the first quartile, median, and third quartile for the 5 clusters were calculated using the reference vectors. Fig. 2 displays the radar charts of the 8 parameters for the 5 clusters with the first quartile, median, and third quartile plotted. As shown in this figure, the visible patterns of Clusters 1 and 5 are similar. Both the clusters have the pattern of low concentrations of all the major ions. In particular, Cluster 1 with the lowest values of all the major ions represents the freshest water type. The highest values of all ions are classified into Cluster 4, which can be assumed that samples in this cluster are of high-salinity type. Clusters 2 and 3 include relatively high values of all cations and Cl^{-}. Furthermore, Cluster 2 is associated with much higher anions of CO_3^{2-} and HCO_3^{-}. In this study, both Clusters 2 and 3 were classified as the low-salinity type.

To summarize, the 5 classified clusters could be divided into three main water types base on the values of all major ions. The freshwater type was associated with Clusters 1 and 3 due to the lowest values in all ions, as indicated in the upper and middle left parts of Fig. 1. Cluster 4 was characterized by the high concentrations of all major ions, representing the high-salinity type, as seen in the lower right of Fig. 1. The remaining 2 clusters (Clusters 2 and 3) are characteristic of the low-salinity type, as shown in the lower left and middle right parts of Fig.1.

Fig.3 shows cluster changes from the dry to rainy seasons. It is observed that 8 out of the 47 observation wells exhibited seasonal changes, in which 4 wells showed changes of water types and the other 4 wells showed changes within the same

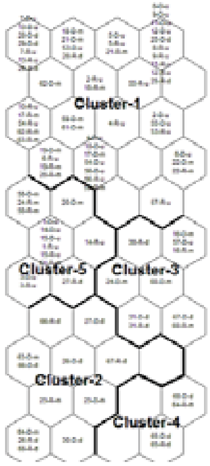

Fig.1 Pattern classification map of the five clusters by the SOM

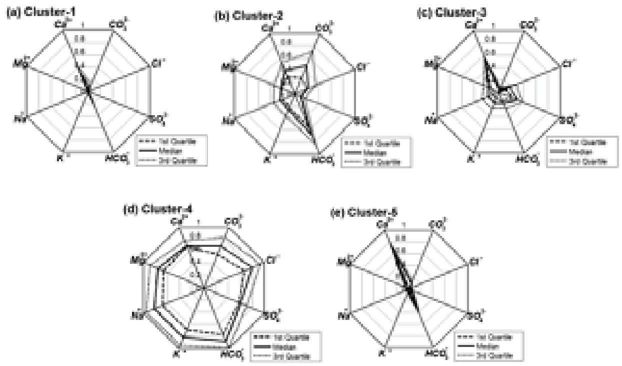

Fig.2 Radar charts for the respective clusters with the first quartile (dashed lines), median (solid lines) and the third quartile (dotted lines) by obtained reference vectors

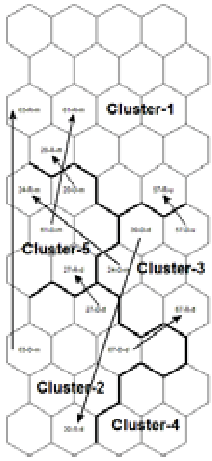

Fig. 3 Cluster changes from the dry to the rainy seasons

water type. Regarding changes in water types, samples from all the 4 wells changed from the low-salinity to the freshwater type. The increase of groundwater recharge, such as rainfall and rivers, may create a dilution effect, which could explain the downward trends in the ion concentrations during the rainy season. In terms of cluster changes within the same water type, it is noted that samples from Well No. 30 changed from Cluster 3 to 2, while Well No. 67 is opposite, from Cluster 2 to 3. On the other hand, samples from Well Nos. 20 and 61 changed from Cluster 5 to Cluster 1 (the lowest salinity). This may be due to the increase of groundwater recharge from surface water such as rainfall, lake or river during the rainy season.

Fig. 4 shows the spatial distribution of the 5 clusters classified by the SOM in the RRD. Cluster 4 (the high-salinity type) is observed in the coastal area, such as Well Nos. 65 and 68. Saltwater intrusion could be the reason for the presence of the high-salinity type in the coastal area. Besides the downstream area, Clusters 2 and 3 are also found in the northeast parts of the upstream and middle-stream areas. The low-salinity type found in the downstream is probably due to the salt water intrusion from the river. On the other hand, with the closer inspection of land use, the wells in northeasts part of the upstream and middle-stream areas are located in an agricultural area of intensive irrigation. Thus, it is reasonable to infer that the presence of the low-salinity type in the upstream and middle-stream areas could be influenced by agricultural activities. Clusters 1 and 5 representing the freshwater type are found not only in the upstream and middle-stream areas but also in the downstream area The presence of freshwater type in the northeast of the downstream area implies that saltwater intrusion does not affect groundwater as far inland as this area. A local lens of freshwater existing in the south of the downstream area may be the reason for the presence of freshwater type found in that area.

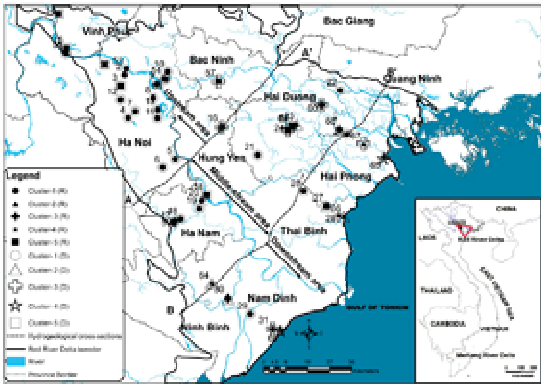

Fig. 4 Distribution of the respective clusters.

5. Conclusions

The SOM application classified the groundwater chemistry data into 5 clusters, which revealed three basic representative water types characterized by the high salinity (Cluster 4), low salinity (Clusters 2 and 3) and freshwater (Clusters 1 and 5). The spatial distribution of clusters and water types were identified. In particular, the low-salinity type samples were found not only in the downstream area but also in the northeastern parts of the upstream and middle-stream areas, where groundwater samples were mainly classified into Cluster 3. With the closer inspection of land use, the groundwater of this cluster was considered to be contaminated by agricultural activities. Cluster changes from the dry to rainy seasons were detected in about one-fifth of the observations wells, where dilution by surface water may significantly affect the chemical characteristics of the unconfined aquifer during the rainy season.

6. References

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