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ANALYSIS OF GROUNDWATER QUALITY USING FUZZY SYNTHESIS EVALUATION

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ABSTRACT - Thriving of the society in Zhengzhou city and development of its economy needs scientific and practical solutions of two main problems; natural water shortage and pollution. It is essential to assess the groundwater quality in order to confirm public safety in Zhengzhou and to reduce contamination in there. Fuzzy Synthetic evaluation was applied to delineate the extent of groundwater contamination in Zhengzhou. Assessment of shallow groundwater results concluded that the first three grades of Chinese water quality standards are 91%, whereas the fourth and fifth grades constitute 9% of it. For the deep water quality, the first two grades are 94% and 6%. It is deduced that part of the shallow groundwater quality is effectively contaminated. Contamination disappears going downward into the deep water. Cluster analysis show exactly same deduction. Fuzzy synthetic evaluation results (using Geographic Information System) were employed to assess the groundwater flow direction around the surveyed wells. It is concluded that infiltration of upstream industrial groundwater is probable into the deep confined groundwater

Keywords: Fuzzy synthetic evaluation, Groundwater quality, Geographic Information System.

INTRODUCTION

Ahn and Chon, 1999, justified three reasons for the gradual demand of groundwater; these are population growth, rapid industrialization, and surface water pollution. Zhengzhou as a Chinese city undergoes severe shortage in water. The per capita water use in Zhengzhou is only 213 m^3 presently and the water shortage is restricting its sustainable development (Li and Chen, 2007). Our assessment of groundwater quality aims to foster rational management of groundwater and prevention of its pollution in the area.

THE STUDY AREA

Zhengzhou municipality includes the city and its constituent counties (figure 1). It is the political, economic, and cultural center of Henan province in China. The rainfall in the study area is mostly between June and September with mean annual precipitation of 641 mm. Most of the 35 rivers in the area belong to the Yellow River and the Huaihe River.

Zhao et al, 2000, defined grade IV for the water quality of the Yellow river from Mengjin to Huayuankou. Water quality of the Yellow River from Mengjin to Huayuankou.

Deng et al, 2006, considered the shallow groundwater as a kind of weakly alkaline fresh water with low Total Dissolved Solid (TDS) 0.37 to 1.48 g/L. The results of chemical analysis of shallow groundwater show that the Total Dissolved Solids, pH range is 7.05 to 8.70 and the total hardness range is 0.24 to 0.59 g/L.

Deep groundwater constitutes a vital supply source for urban and industrial development in the Zhengzhou area (Li et al, 2005).

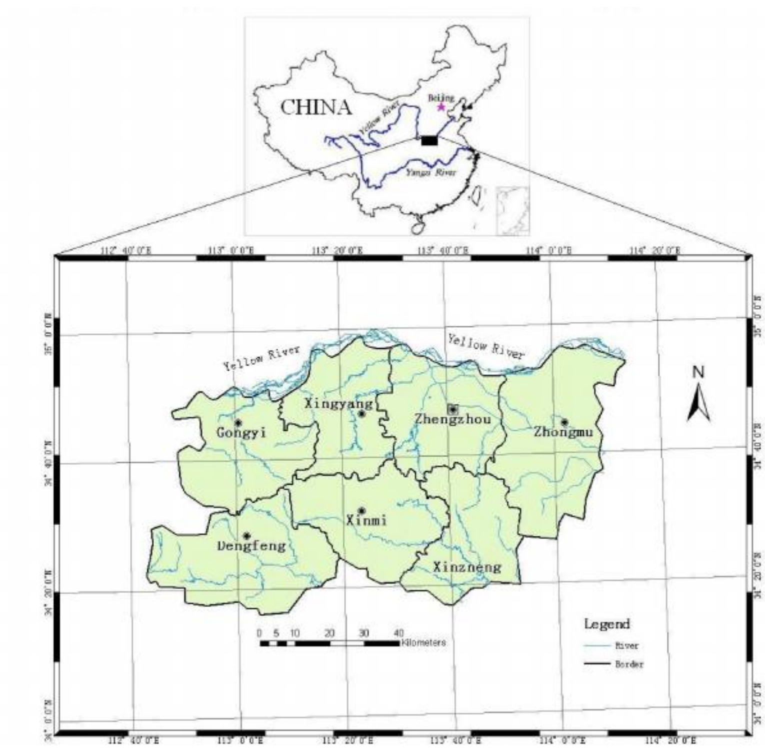

Fig.(1):- Location map of the study area

SAMPLING AND CLUSTER ANALYSIS

In order to deduce potentially contaminated areas, Cluster analysis is applied. This multivariate statistical analysis is accomplished by using groundwater quality standards (GB/T14848-93). Cluster variables include TDS, total hardness, SO_4^{2-} and Cl^- . Groundwater samples were collected in June & September 2005, 45 from shallow and 31 from deep wells. Figure 2, shows the locations of the 76 wells. An extra special sample was added to these 76 wells. It is numbered GB00 and its variables are: TDS= 2000 (mg/L), total hardness = 550 (mg/L), SO_4^{2-} = 350 (mg/L) and Cl^- = 350 (mg/L). These values are indications of water grade worse than grade V (according to the groundwater quality standards). We selected Q-cluster for the sample data by the K-means cluster method.

The data matrix was divided into two groups to determine the various classes of groundwater quality. Group I includes the points D03, G06, X03, D04, M01, A02, and GB00. Group II includes the rest 70 sample points. Apparently, the shallow groundwater of group I is not drinkable. As there is no samples from deep confined water at group I area, we provisionally assume that the deep confined water is non-polluted good quality water.

Fig.(2):- Location of sampling points.

FUZZY SYNTHETIC EVALUTION

The pollution of groundwater and assessment of its quality based on environmental standards pollution is a fuzzy issue. Fuzzy mathematical methodology describes exactly the fuzzy boundaries for water quality by constructing a membership function of water quality categories (GB/T14848-93). It is a very promising evaluation method that reflects the actual situation of groundwater quality. On application of this method more attention should be paid to the selection of weights and the fuzzy operator. Further study is needed on how to determine the weights among the evaluation indices of groundwater quality.

Comparatively, the natural single index method can objectively reflect the degree of influence of standard pollution factors on water pollution. Su and Su, 2007, mentioned that this method does not take into account the fact that there is different influence on water quality by various factors.

Four basic elements of pollution were selected to build a single factor indicator U (where U is TDS, Total hardness, SO_4^{2-}, Cl^-). These four factors can accurately reflect the changes in the groundwater quality and describe its characteristics. Moreover, the four indicators are irrelevant to each other and easy to measure. A five-grade set foe water quality standards K is established (K =k_1, k_2, k_3, k_4, k_5). Where, k_i is respected as the correspondent value to the four pollution quality grading standards. The next step was nesting a fuzzy matrix R [r_{ij}], which can reflect the transforming relationship among the members of K, set by the evaluation factors. As a final step, and in order to establish a membership function, the "drop-half trapezoidal distribution" was applied:

$$r_{ij} = \begin{cases} 1 & X_i \le A_{ij} \\ \dfrac{(A_{ij+1} - X_i)}{A_{ij+1} - A_{ij}} & A_{ij} < X_i \le A_{ij+1} \\ 0 & A_{ij+1} < X_i \end{cases} \quad (1)$$

where X_i is the measured concentration of the water evaluation factor
A_{ij} and A_{ij+1} are the groundwater quality standard values of two adjacent grades.

According to the 1993 Edition of the groundwater quality standards of China (GB/T14848-93), one can substitute the groundwater quality standard values of TDS, total hardness, SO_4^{2-}, Cl^- in Equation (1) to obtain the membership functions of different factors. The memberships of all the sampling points can be calculated by using FIS Tool Box of MATLAB. In the evaluation process, different quality factors have different contributions to pollution;

therefore various factors can be given different weights based on the function in the assessment. The weights should be normalized as follows:

$$W = \frac{C_i / S_i}{\sum_{i=1}^{n} (C_i / S_i)} \qquad (2)$$

Where C_i is the measured value of *i*th factor (mg/L), S_i is the standard value of *i*th factor and its value is the average of all classes' standard values (mg/L), *n* is the number of the factor, and W_i is weight of *i*th factor.

The values of normalized weight factors have been used to build weight matrix A. After building *A* and *R*, we then chose the operator (·, ⊕), which is the weighted and summing operator to obtain the fuzzy synthetic evaluation results. This operator may weaken the function of the main factors, but it can make full use of the information. The results of fuzzy math were employed to establish a classification map for the groundwater quality in Zhengzhou city. This was achieved by applying MAPGIS (a Chinese version of GIS developed by the China University of Geosciences). The map will furnish a more direct and simple way to analyze and explain the water quality data (Figure 3).

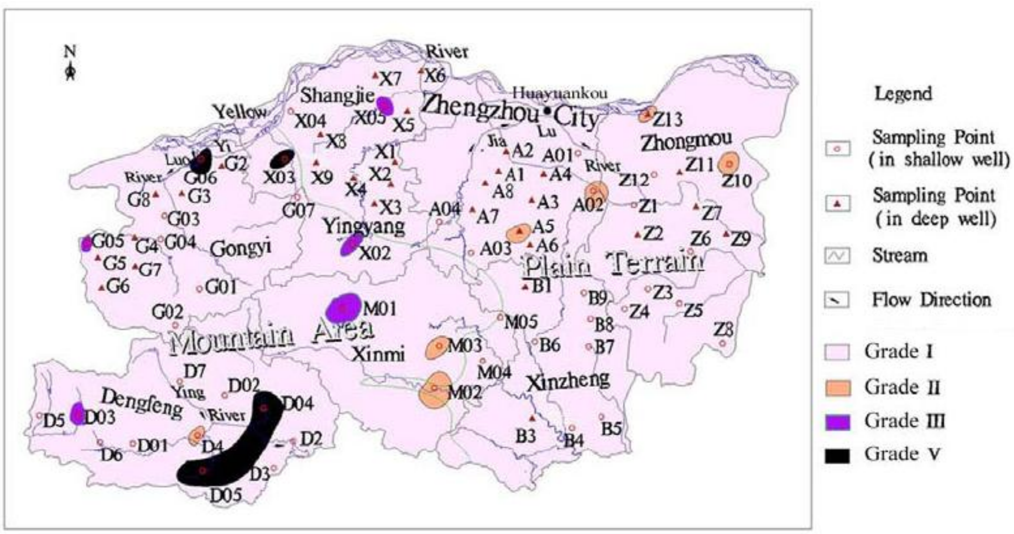

Fig.(3):- Classification of shallow groundwater quality.

RESULTS AND DISCUSSION

The results show that the grades I, II, III, IV, and V compose 64%, 16%, 11%, 0%, and 9% of the shallow groundwater respectively. For the deep groundwater, grades I and II constitute 94% and 6% respectively. The Results indicate that part of the shallow groundwater is bad, whereas most of the deep confined water is of good quality. These results coincide with the results of cluster analysis results discussed earlier. Those points in the shallow groundwater with a quality worse than grade III, were sampled in September which represents the end of the rainfall season. The shallow groundwater quality could be the worst at this time of the year due to precipitation recharge, which may feed the groundwater with more contaminants.

The sample points were reproduced on a geographical map by using the projection function of MAPGIS to read the longitudes and latitudes of the points. Judgment of the water flow direction around each point could be achieved from readings of elevations from the geographical maps. Shallow groundwater quality for points G05, G06, X03, and X05 nearby Yellow River is bad. All of the sample points were worse than grade III.

The water quality at point X03 is worse than grade V due to the industrial wastewater generated by an abrasives factory, situated some where between points X03 and X04. The shallow groundwater quality for points D04 and D05 is worse than grade V also. These two points are in the lower Ying River. The deep groundwater at point Z13 is of grade II, which may be produced from the grade IV water of the Yellow River at Huayuankou.

Apart from points A5, all the points from A1 to A8 registered grade I for deep confined water. Point A5 registered grade II as its deep groundwater has probably been affected by the industrial wastewater from Zhengzhou Yu-Tong Passenger Automobile Co. Ltd. and the Zhengzhou Qian Yuan-hao Biology Pharmacy Factory (near point A6). Figure 2 shows that A5 is on the backward position of A6.

CONCLUSIONS

Assessment of groundwater quality at 76 sampling points using Fuzzy Evaluation method yielded:

- 91% of shallow groundwater is composed of grades I, II, and III, whereas the rest 9% is graded at V and V.
- 94% of deep groundwater is of grades I, whereas the rest 6% is graded at II.
- The above indicates that part of the shallow groundwater can not be used as drinking water, while most of the deep groundwater is potable.
- Shallow water quality downstream of the main rivers is poor as a result of industrial wastewater. Some of the wastewater has even infiltrated into deep confined aquifers. In summary, long-term utility of low quality water is risky on the health of local residents.

- The selected four natural factors (TDS, total hardness, SO_4^{-2} and Cl^-) to assess the groundwater quality can basically reflect the natural background of the groundwater quality. However, different assessment methods or different selected factors may yield different results.

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تحليل نوعية المياه الجوفية باستخدام تقييم فزي المركب

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الخلاصة

النمو الاجتماعي والاقتصادي في مدينة جينغ جو يحتاج إلى حلول تطبيقية لمشكلتين أساسيتين هما: نقص المياه وتلوثها، لذلك أصبح من الضروري تقييم نوعية المياه الجوفية في المنطقة من اجل ضمان سلامة المياه وتقليل التلوث فيها. تم استخدام التقييم المركب (Fuzzy Synthetic) لتحديد امتداد تلوث المياه الجوفية في منطقة جينغ جو. أظهرت النتائج بان الدرجات الثلاثة الأولى (استنادا إلى المعيار الصيني لنوعية المياه الجوفية) تشكل نسبة ٩١% بينما الدرجات الرابعة والخامسة تشكل نسبة ٩% بالنسبة للمياه الجوفية الضحلة. أما بالنسبة للمياه الجوفية العميقة فان الدرجتين الأولى والثانية تشكل نسبة ٩٤% و ٦% على التوالي. النتائج أظهرت أيضا أن جزء من المياه الجوفية الضحلة ملوثة بشكل مؤثر ولكنه يزول باتجاه الأسفل نحو المياه الجوفية العميقة. التحليل العنقودي (Cluster Analysis) اظهر تماما نفس الاستنتاجات. بالاعتماد على نتائج التقييم المركب وباستعمال برنامج نظم المعلومات الجغرافية لتقييم اتجاه تدفق المياه الجوفية حول أبار الفحص استنتجنا أن مياه الفضلات الصناعية المنتقلة خلال مجرى الأنهار تكون قد تعرضت للتصفية أثناء ترشحها في خزانات المياه الجوفية المحصورة العميقة.

الكلمات الدالة: تقييم فزي المركب، نوعية المياه الجوفية، نظم المعلومات الجغرافية