ARTICLE IN PRESS

Environmental Pollution xxx (2016) 1–10

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

# Identification of the hydrogeochemical processes and assessment of groundwater quality using classic integrated geochemical methods in the Southeastern part of Ordos basin, China

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ARTICLE INFO

*Article history:*
Received 2 June 2016
Received in revised form
29 July 2016
Accepted 4 August 2016
Available online xxx

Handling editor: Harmon Sarah Michele

*Keywords:*
Hydrogeochemistry
Water quality assessment
Ionic ratio coefficient
PCA
Southeastern part of Ordos basin

ABSTRACT

Insufficient understanding of the hydrogeochemistry of aquifers makes it necessary to conduct a preliminary water quality assessment in the southern region of Ordos Basin, an arid area in the world. In this paper, the major ions of groundwater have been studied aiming at evaluating the hydrogeochemical processes that probably affect the groundwater quality using 150 samples collected in 2015. The two prevalent hydrochemical facies, $HCO_3$–Mg·Na·Ca and $HCO_3$–Mg·Ca·Na type water, have been identified based on the hydrochemical analysis from Piper trilinear diagram. Compositional relations have been used to assess the origin of solutes and confirm the predominant hydrogeochemical processes responsible for the various ions in the groundwater. The results show that the ions are derived from leaching effect, evaporation and condensation, cation exchange, mixing effect and human activities. Finally groundwater quality was assessed with single factor and set pair methods, the results indicate that groundwater quality in the study region is generally poor in terms of standard of national groundwater quality. The results obtained in this study will be useful to understand the groundwater quality status for effective management and utilization of the groundwater resource.



## 1. Introduction

Water shortage has become an increasingly serious problem in China, especially in arid and semi-arid zones, groundwater plays a major role in the water supply of arid and semiarid regions, and is gaining increasing importance in the supply of water to rural communities. It is estimated that approximately one-third of the world's population use groundwater for drinking (Nickson et al., 2005). Knowledge on hydrogeochemical characteristics plays an important role in assessing the groundwater quality to understand its suitability for various purposes. Therefore, it is necessary to understand the hydrochemical characteristics of the groundwater and its evolution under natural water cycle processes for sustainable development and effective groundwater management (Wen et al., 2005; Tizro and Voudouris, 2008; Chang and Wang, 2010). The groundwater chemistry depends on different hydrogeochemical processes that the groundwater undergoes over space and time. The variation of groundwater quality is the combined effects of natural and anthropogenic factors, such as geological structure where groundwater is stored, composition of precipitation, the interaction between the groundwater and aquifer minerals like oxidation/reduction, cation exchange, precipitation/dissolution of minerals, mixing of waters, leaching of fertilizers, manure, biological and micro-biological process, and human activities. The interaction of these factors result in various groundwater types. Hydrogeochemical study is usually considered to be useful in identifying these processes that control groundwater hydrochemistry (Jeevanandam et al., 2007). Generally, the ions of groundwater is controlled by many factors that include recharged water, atmospheric precipitation, and inland surface water and on subsurface geochemical processes. The interaction of all factors leads to various water types. The increased knowledge of geochemical processes can help to understand the groundwater hydrogeochemical systems.

Research on water quality and hydrochemistry has been widely conducted over the world due to the increasing awareness of water

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http://dx.doi.org/10.1016/j.envpol.2016.08.017
0269-7491/

Please cite this article in press as: Yang, Q., et al., Identification of the hydrogeochemical processes and assessment of groundwater quality using classic integrated geochemical methods in the Southeastern part of Ordos basin, China, Environmental Pollution (2016), http://dx.doi.org/10.1016/j.envpol.2016.08.017

quality protection. In recent years, many works are focused on the study of natural water and environment of the northern part of Ordos Basin, understanding the relationships between water and environment, water and development, and recognizing how to practice sound water management (Dong et al., 2008; Su et al., 2009; Hou et al., 2006). And the groundwater quality in the southeastern part of Ordos Basin has received little attention for decades, and no international literature can be viewed up to date. The southern part of Ordos Basin is predominantly covered by loess with broken terrains and strong cuttings. The scarce precipitation and strong evaporation result in the sparse vegetation in most part of the area, subsequently desertification and soil erosion gives rise to the fragile eco-environment. At present, water shortage has become a hinder of local economic development. Therefore, the investigation of hydrochemistry of this area has become a high-priority concern to the whole community. Therefore, a comprehensive hydrogeochemical study is necessary to identify the chemical processes that affect the groundwater quality of this area. Under these circumstances, a national research project named "Investigation on Groundwater Pollution in Ordos Basin" was carried out in 2015 at the southeastern part of Ordos Basin to interpret the chemistry of groundwater and assess the groundwater quality.

This paper is constructed with an effort to interpret the main hydrogeochemical processes controlling groundwater compositions in the southeastern Ordos Basin using Piper trilinear diagram, ionic ratio coefficient, principal component analysis, and further to assess groundwater quality with single factor analysis and set pair evaluation methods.

## 2. Study area

The Ordos Basin is located in the middle reaches of the Yellow River in the northwest of China. It is surrounded by mountains all sides, Qinling, Yinshan, Lv Liangshan, Helan - six panshan mountains in north, south, east and west, respectively. The region of this study is the southeastern part of Ordos Basin, which lies between 108°12′-111°17′ E and 34°26′-37°29′ N, covering a total area of 67781 $km^2$. The area is mainly covered by loess and Pliocene mudstone with broken terrain and typical cutting, which is not favorable to recharge. Due to the asymmetry of the total basin, the carboniferous - Jurassic clastic rock underlying (the top of Paleozoic carbonatite) outcropped at the southeast of the basin as an unconformable denudation, the aquifer is usually cut through by surface water and can get recharged from surface water and precipitation. The main water system from west to East followed by Cambrian - Ordovician karst water system, Cretaceous groundwater system, Carboniferous and Jurassic fissure water and overlying loose pore water system with poor hydraulic connection. The area is characterized with continentally arid and semi-arid climate.

## 3. Sampling and analytical procedure

### 3.1. Sample collection and measurement

150 water samples were collected from 150 wells during June to July 2015 in the Southeastern part of the Ordos Basin. Fig. 1 shows the locations of the selected wells. These wells are numbered from 1 to 150. All these samples were analyzed in the laboratory for major ions. During sample collection, handling, and preservation, standard procedures recommended by the Standard Examination Methods for Drinking Water were followed to ensure data quality and consistency (Ministry of Health of the People's Republic of China (2006)). Charge balanced-alkalinity (alkalinity hereafter) was calculated by $[Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}] - [Cl^-] - [NO_3^-] - [SO_4^{2-}]$ in mmol/l (Reuss and Johnson, 1986). The analytical precision for the measurements of ions was determined by the ionic balances, calculated as 100 × (cations − anions)/(cations + anions), which is generally within ±5%.

### 3.2. Analytical methods

Piper diagram is one of the most effective graphic representation in the study of the groundwater quality, which helps to understand the groundwater geochemical characteristics. In this paper, the water chemical analysis software AquaChem V4.0 was used to draw the piper diagram of the selected samples, which can directly reflect the general chemical characteristics of water samples and the relative content of various ions (Purushotham et al., 2011; Hong, 2012). Ionic ratio coefficient method and principal component analysis method were applied to chemical data for analyzing the main characteristics of ion composition and ion proportion in groundwater, so as to determine the geochemical process of groundwater.

In order to determine the suitability in terms of domestic and agricultural purposes, Single factor analysis and set pair evaluation method are two commonly used methods in groundwater quality assessment. In order to improve the accuracy of assessment results of groundwater quality, single factor analysis method was performed first. That is, the analysis and evaluation of each index in all samples were carried out in accordance with the "groundwater quality standards" DZ/T 0209-2015 (Ministry of Land and Resources of P. R. China, 2015) and the final evaluation class is determined using the highest level of groundwater samples. The second step is performing set pair method by selecting the components which have an important effect on water quality as evaluation factors. Finally, GIS was used to show visually the evaluation results.

## 4. Results and discussion

### 4.1. Groundwater chemistry

#### 4.1.1. Hydrochemical facies

Hydrochemical facies is a term used to describe the quantities of water differing in their chemical compositions, which is a combined effects of solution kinetics, rock-water interactions, hydrogeological settings and contamination sources. A convenient method to determine groundwater types based on ionic composition, Piper trilinear diagram, was proposed by Piper (1944), which consists of a diamond and a pair of equilateral triangles, two triangles are respectively represent the anion and cation and the two triangles are connected by a diamond shaped diagram. The Piper diagram was constructed using AquaChem V4.0, which can visually show the relative concentrations of the different ions of each water sample. The chemical groundwater types of the study area were distinguished and grouped by their position on a Piper diagram (Fig. 2). Based on the major cation and anion, 5 major hydrochemical facies were identified, they are: $HCO_3$—Mg·Na·Ca, $HCO_3$—Mg·Ca·Na, $HCO_3$—Ca·Mg, $HCO_3$—Na·Mg·Ca, and $HCO_3$— Na·Mg types.

#### 4.1.2. Descriptive statistics

Cv (Coefficient of variation) is usually used to characterize the stability of variable. When the 0 < Cv < 10 percent for weak mutation; 10% < Cv < 100% for moderate variability; Cv>100% strong variation. In this paper, the statistical analysis results of 150 groundwater samples in 2015 for each water quality parameter from study area are presented in Table 1.

The pH value in the study area ranges from 7.17 to 8.32 with a mean value of 7.74 and standard deviation of 3.4%, indicating a weakly alkaline environment. These values were found to be in the