Analysis of Hydrogeochemical Evolution of Groundwater in the Eastern Plain Area of Changji Prefecture, Xinjiang (Postprint)

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Abstract

To investigate the evolution process of groundwater quality in the eastern plain area of Changji Prefecture, Xinjiang, mathematical statistics, Piper trilinear diagrams, Gibbs diagrams, and ion ratio methods were employed to analyze 63 groundwater quality sampling points in 2016 and 54 groundwater quality monitoring data sets from 2012 to 2015 in the eastern plain area of Changji Prefecture. The results indicate that in the eastern plain area of Changji Prefecture, the average content of groundwater cations in 2012 was generally Ca2+>K++Na+>Mg2+, and the average content of anions was generally HCO3->SO42->Cl-; starting from 2013, SO42- gradually increased while Ca2+ gradually decreased; by 2016, the average content of cations was generally Ca2+>K++Na+>Mg2+, and the average content of anions was generally HCO3->SO42->Cl-. The hydrochemical type evolved from the HCO3–Ca · Mg (Ca · Na, Ca · Na · Mg) type in 2012 to HCO3 · SO4–Ca · Na · Mg (Ca · Mg, Ca · Na) in 2016, which is mainly related to the weathering of aquifer media and evaporation concentration, with the evaporation concentration being more evident in the upper phreatic water of the confined water area. Na+, K+, and Cl- in groundwater mainly originate from the dissolution of rock salt; Ca2+ and Mg2+ mainly originate from the dissolution of evaporite rocks; SO42- mainly originates from the dissolution of gypsum (CaSO4 · 2H2O) and mirabilite (Na2SO4 · 10H2O). In addition to originating from the dissolution of rock salt, Cl- and SO42- are also affected by human activities.

Full Text

Hydrogeochemical Evolution Process of Groundwater in the Eastern Plains of Changji Hui Autonomous Prefecture, Xinjiang

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Abstract: This study analyzed test data from 63 groundwater samples collected in 2016 and 54 water quality monitoring data points from 2012–2015 in the eastern plains of Changji Hui Autonomous Prefecture, Xinjiang, using mathematical statistics, Piper diagrams, Gibbs plots, ion ratios, and other methods. The purposes were to explore the evolution process of groundwater hydrochemistry in the study area. The results showed that the average cationic concentrations of groundwater in the study area in 2012 were in the order of Ca^{2} > K + Na > Mg^{2}, and the average anionic concentrations were in the order of HCO > SO^{2} > Cl. After 2013, the concentration of SO^{2} gradually increased while that of Ca^{2} gradually decreased. By 2016, the average cationic concentrations were Ca^{2} > K + Na > Mg^{2}, and the average anionic concentrations were HCO > Cl > SO^{2}. The hydrochemical type evolved from HCO · Ca · Mg (Ca · Na, Ca · Na · Mg) in 2012 to HCO · SO · Ca · Na · Mg (Ca · Mg, Ca · Na) in 2016, which was mainly related to evaporation and rock weathering of the aquifer medium, with evaporation reflected more prominently in unconfined groundwater. Na, K, and Cl in groundwater came mainly from the dissolution of rock salt; SO^{2} came mainly from the dissolution of gypsum (CaSO · 2H O) and mirabilite (Na SO · 10H O). In addition to the dissolution of rock salt, Cl and SO^{2} are also affected by human activities.

Keywords: plain; groundwater; hydrogeochemistry; evolution; Changji; Xinjiang

1. Introduction

The eastern plains of Changji Hui Autonomous Prefecture are located in the hinterland of the Eurasian continent, characterized by a typical temperate continental arid climate. The region has an average annual precipitation of 190.0 mm and evaporation of 1900.0–2700.0 mm, with a temperature range of 5–7.5°C and a groundwater depth of 3–4‰. Groundwater serves as the primary water source for agricultural irrigation, industrial production, and domestic use in this area. Understanding the hydrochemical evolution of groundwater is crucial for sustainable water resource management and environmental protection.

2. Materials and Methods

2.1 Study Area

The study area is situated in the eastern plains of Changji Hui Autonomous Prefecture, Xinjiang. Groundwater monitoring wells were distributed across the region to capture spatial variations in hydrochemistry [Figure 1: see original paper]. The hydrogeological profile reveals a multi-layered aquifer system typical of alluvial plains [Figure 2: see original paper].

2.2 Data Collection

Water quality monitoring data from 2012–2015 were obtained from 54 monitoring wells. In 2016, groundwater samples were collected from 63 wells (35 unconfined and 28 confined) following the *Technical Specifications for Groundwater Monitoring* (DZ/T 0288-2015). Sampling locations are shown in [Figure 2: see original paper]. Water samples were collected in 1000 mL polyethylene bottles, filtered through 0.45 m membranes, and acidified to pH < 2 for cation analysis. Field parameters including pH, temperature, and electrical conductivity were measured in situ.

2.3 Water Quality Analysis

All analyses were conducted at the Xinjiang Center for Hydrology and Water Resources Engineering Research following the *Standard Examination Methods for Drinking Water* (GB/T 5750-2006) and *Technical Specifications for Groundwater Environmental Monitoring* (HJ/T 164-2004). Analytical parameters included pH, K , Na , Ca^{2} , Mg^{2} , Cl , SO^{2} , HCO , CO^{2} , total hardness (TH), and total dissolved solids (TDS). Detection limits were 0.01 mg·L^{1} for Na , 0.05 mg·L^{1} for K , 1.0 mg·L^{1} for Ca^{2} , Mg^{2} , Cl , SO^{2} , and HCO , and 5.0 mg·L^{1} for TDS. Analytical precision was maintained within ±5% relative error.

3. Results and Discussion

3.1 Hydrochemical Characteristics

The statistical results of groundwater hydrochemical parameters from 2012–2016 are presented in . In 2012, the dominant cations were in the order $Ca^{2} > K + Na > Mg^{2}$, while anions followed $HCO > SO^{2} > Cl$. After 2013, TDS concentrations increased significantly, with SO^{2} becoming more dominant. By 2016, the cationic order remained $Ca^{2} > K + Na > Mg^{2}$, but the anionic sequence shifted to $HCO > Cl > SO^{2}$.

Piper diagrams [Figure 4: see original paper] illustrate the evolution of hydrochemical facies. In 2012, groundwater was primarily of the HCO ·Ca·Mg type (with some Ca·Na and Ca·Na·Mg variants). By 2016, the dominant type evolved to HCO ·SO ·Ca·Na·Mg (with Ca·Mg and Ca·Na sub-types), indicating increasing sulfate influence.

3.2 Correlation Analysis

Pearson correlation analysis was performed using SPSS software. Correlation coefficients (R) were interpreted as: 0.0–0.2 (negligible), 0.2–0.4 (weak), 0.4–0.6 (moderate), 0.6–0.8 (strong), and 0.8–1.0 (very strong). In unconfined groundwater , SO^{2} showed very strong correlations with K + Na (R = 0.87) and Ca^{2} (R = 0.84). Cl was very strongly correlated with Ca^{2} (R = 0.83), while Ca^{2} and Mg^{2} showed strong correlation (R = 0.73). These relationships suggest common sources and geochemical processes controlling ion distributions.

In confined groundwater , similar correlation patterns were observed, though some relationships differed in strength, reflecting the influence of aquifer confinement on hydrochemical evolution.

3.3 Evolution Mechanisms

Gibbs Analysis: Gibbs plots [Figure 5: see original paper] were constructed using TDS versus Na / (Na + Ca^{2}) and Cl / (Cl + HCO). Most samples plotted in the rock weathering and evaporation dominance zones, with TDS ranging from 100–1200 mg · L^{1}. The ratio Na / (Na + Ca^{2}) approached 0.5, while Cl / (Cl + HCO) varied between 0.5 and 1.0, indicating that evaporation and rock weathering are the primary processes controlling groundwater chemistry, particularly in unconfined aquifers.

Ion Ratio Analysis: The relationship between (SO^{2} + Cl)/ HCO and (Ca^{2} + Mg^{2})/ HCO [Figure 6a: see original paper] shows that most samples fall along the 1:1 line, suggesting carbonate and silicate weathering dominate. The (Na + K)/ Cl ratio [Figure 6b: see original paper] approaches 1.0, indicating rock salt dissolution as the primary source of Na , K , and Cl . The (Ca^{2} + Mg^{2})/ HCO ratio [Figure 6c: see original paper] exceeds 1.0, suggesting additional sources of Ca^{2} and Mg^{2} beyond carbonate dissolution, likely from gypsum weathering.

Mineral Saturation Indices: PHREEQC modeling calculated saturation indices (SI) for key minerals [Figure 7: see original paper]. Most samples were undersaturated with respect to halite (SI < 0), indicating active dissolution. Calcite and dolomite showed near-equilibrium to oversaturated conditions (SI 0 to > 0), while gypsum was generally undersaturated. The positive correlation between TDS and SI values confirms that evaporation concentrates dissolved ions, driving mineral precipitation.

The distribution of Cl and SO^{2} [Figure 8: see original paper] reveals spatial patterns consistent with both natural geochemical processes and anthropogenic inputs, particularly in agricultural areas where fertilizer application and irrigation return flow contribute to elevated sulfate concentrations.

4. Conclusions

(1) Groundwater hydrochemistry in the eastern plains of Changji evolved significantly from 2012-2016. The dominant cations remained Ca^{2} > K + Na > Mg^{2}, while anions shifted from HCO > SO^{2} > Cl to HCO > Cl > SO^{2}. The hydrochemical type evolved from HCO · Ca · Mg in 2012 to HCO · SO · Ca · Na · Mg in 2016.

(2) Evaporation and rock weathering are the primary processes controlling groundwater evolution, with evaporation effects more pronounced in unconfined groundwater. Na, K, and Cl originate mainly from rock salt dissolution, while SO^{2} derives from gypsum and mirabilite dissolution.

(3) Human activities, particularly agricultural practices, significantly affect Cl and SO^{2} concentrations, superimposed on natural geochemical processes.

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