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Hydrochemical variation characteristics and driving factors of surface water in arid Areas—a case study of Beichuan River in Northwest China

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Examining the chemical properties of river water and the controlling factors is crucial for devising efficacious strategies in water resources management and ecological conservation. This study investigates the hydrochemical characteristics and driving factors of the Beichuan River in the arid region of Northwest China. Surface water samples were collected during wet and dry seasons, and analyzed using hydrochemical diagrams, mathematical statistics, and principal component analysis (PCA). The results show that the pH value of Beichuan River is generally weakly alkaline, the main hydrochemical types are HCO_3-Ca, and the average TDS are 224 mg/L and 236 mg/L respectively, which are higher than the world average level (115 mg/L). The seasonal variation of hydrochemical components is mainly controlled by rainfall, showing that the concentrations of Na^+, Cl^- and NO_3^- in the wet season are higher than those in the dry season, while the concentrations of other chemical components show an opposite trend, while the spatial variation is mainly controlled by human activities, and the concentrations of hydrochemical components show a gradual increasing trend from upstream to downstream, especially Na^+, Mg^{2+}, Cl^- and NO_3^-. Rock weathering is the key natural factor controlling the Hydrochemical Composition of Beichuan River. Na^+ and Cl^- are mainly from the dissolution of silicate, Ca^{2+} and Mg^{2+} are mainly from the weathering of carbonate rocks and silicate, and SO_4^{2-} is mainly from the dissolution of evaporite. It is noted that human activities, especially domestic sewage and agricultural runoff, contribute significantly to NO_3^- in the water body. PCA identified rock weathering and agricultural runoff as major wet-season factors, while domestic sewage predominantly affects the dry season. This study can provide a scientific basis for the rational development of water resources and ecological environment protection in arid areas.

KEYWORDS

arid area, rivers, hydrochemistry, control factors, human activities

1 Introduction

As conduits between the sea and land, rivers serve as indispensable in the earth's material circulation and energy flow (Moquet et al., 2016). It is not only an important part of the ecosystem, but also an important human resource. However, in recent years, with the rapid development of social economy, the impact of human activities on river water chemistry has become increasingly significant, resulting in the degradation of river ecological functions and, consequently, posing a threat to the ecological value of rivers as well as to human health and wellbeing (Zhang Q. Q. et al., 2024; Jiang et al., 2021). It is very important to study the chemical characteristics of river water and its influencing factors for formulating effective water resources management and ecological protection strategies (Zhang X. et al., 2024).

There are many factors affecting river water chemistry, such as climatic conditions, geological conditions, vegetation and land use (Maavara et al., 2020; Tang and Liu, 2011). Researchers both domestically and internationally have done a lot of research work. Kattan (2015) conducted a hydrochemical analysis of the Euphrates River in Syria and noted that the ion composition in the river was mainly controlled by the weathering and dissolution of rocks, water temperature and evaporation process. Pant et al. (2018) in their study of Gandaki River in Nepal, suggested that the weathering dissolution and evaporation concentration of carbonate were the main factors controlling the ion composition of river water. Scholars have conducted research on the hydrochemistry of major rivers in eastern China, including the Yangtze River, the Yellow River, the Pearl River (Chen et al., 2006; Jia et al., 2021; Liu et al., 2020; Xuan et al., 2018) and found that atmospheric precipitation and rock weathering are the main natural factors affecting the hydrochemical composition. In addition, the impact of human activities on river water chemistry cannot be ignored. Researchers observed that the hydrochemistry of the Yellow River was significantly affected by industrial and agricultural activities in the basin (Ren et al., 2024). Zhang et al. (2017) found strong spatial differences in NO_3^--N and NH_4^+-N in the Fuyang River, with higher concentrations near urban areas and lower concentrations further away from the city.

Beichuan River basin, serving as the primary drinking water source in Xining City, exerts a profound impact on the local ecological environment and socio-economic development. The basin is located in the arid area of Northwest China, and its hydrochemical variation and controlled factors may be significantly different from those in other regions. Although existing studies have addressed the hydrochemical characteristics of groundwater in Beichuan river basin to a certain extent (Yang et al., 2023; Zhu et al., 2022), research on the hydrochemical characteristics of surface water and its control factors remains limited. To address this gap, this study systematically collected the surface water samples of Beichuan River and analyzed the hydrochemical variation characteristics and driving factors of surface water by using hydrochemical diagram, mathematical statistics and principal component analysis. The findings are expected to provide crucial scientific basis for the rational development of water resources and ecological environment construction in Beichuan River Basin.

2 Materials and methods

2.1 Overview of the study area

Beichuan River originates from Datong Hui Autonomous County, Xining City, Qinghai Province, China, and is formed by the convergence of Baoku River, Heilin River and Dongxia River. After traversing the whole territory of Datong County, the river flows through Xining city and finally flows into Huangshui River, which is the primary tributary of Huangshui River and the secondary tributary of the Yellow River (Xiao et al., 2020). Beichuan River has a total length of 154.2 km and a drainage area of 3371 km^2. The whole basin has a semi-arid continental climate, with an average annual precipitation of 367.5 mm, mainly from May to September (Wang et al., 2019). The land use types in this area are relatively complex, mainly including cultivated land (12.4%), forest and grassland (63.7%), construction land (6.78%), water area (0.15%) and unused land (43.4%). According to the characteristics of human activities in the Beichuan River Basin, the Beichuan River was divided into upstream (R01-R09) (The upstream of the study region is primarily dominated by forest and grassland), midstream (R10-R17) (the midstream of the study region is located in Datong County with a population density of 142 people/km^2) and downstream (R18-R26) (the downstream of the study region is located in Xining City, with a population density of 331 people/km^2). The location of sampling points is shown in Figure 1.

2.2 Sample collection and testing

In order to study the chemical characteristics of Beichuan River and the sources of its main ion components, 26 surface water samples were collected respectively in July 2019 (wet season) and October 2019 (dry season). At each site, water samples were collected from the midpoint of a bridge spanning the river using a polyethylene surface water sampler. The polyethylene sampling bottles were then triple-rinsed with the river water. Collection was typically performed below 50 cm from the water surface. Each sample was divided into two aliquots: one for the determination of cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}), to which reagent-grade nitric acid was added on-site to acidify the solution to a pH < 2; the other for the determination of anions (HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-), with no additives used. Ensure that all samples are filled with the entire container, refrigerated without bubbles and kept away from light. The sample analysis and testing were completed by the testing center of Institute of hydrogeology and environmental geology, Chinese Academy of Geological Sciences. All samples were tested within 1 week after collection. The pH was measured on site with a portable multi parameter water quality tester (HACH HQ40d, Loveland, CO, United States of America) and the detection limit values were 0.01 mg/L, the total dissolved solids (TDS) was measured by drying method, and the cations K^+, Na^+, Ca^{2+} and Mg^{2+} were measured by atomic absorption spectrophotometer (Agilent 7500ce, ICP-MS, Tokyo, Japan) and the detection limit values were 0.05 mg/L, 0.01 mg/L, 4.0 mg/L and 3.0 mg/L, respectively. Anions SO_4^{2-}, Cl^- and NO_3^- were determined by ion chromatography (Perkin ElmerLambda 35, Waltham, Ma,

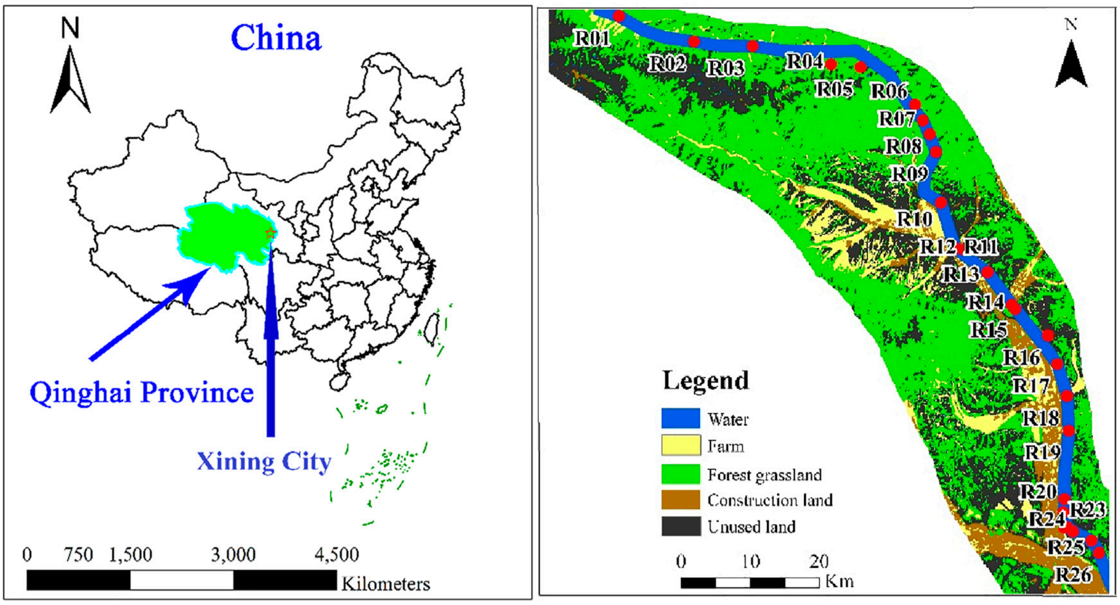

FIGURE 1
Distribution of sampling points in Beichuan River Basin.

United States of America) and the detection limit values were 0.75 mg/L, 1.0 mg/L and 0.664 mg/L, respectively. HCO_3^- was determined by hydrochloric acid titration and the detection limit value was 5.0 mg/L.

2.3 Data analysis method

In this study, ArcGIS 10.5 was used to draw the sampling points in the study area; Use Excel to calculate the mean and standard deviation of water sample test data; Origin 2022 was used to draw the ion ratio diagram and analyze the correlation of hydrochemical components (significance level 0.05); Finally, SPSS 25.0 was used to standardize the surface water data of Beichuan River Basin in wet and dry seasons, and then the Principal Component Analysis (PCA) of hydrochemical components was carried out.

PCA is an exceedingly effective method for dimensionality reduction within a dataset that encompasses a multitude of interrelated variables, aiming to preserve the maximal variability inherent in the data. Prior to integrating the data into the PCA model, the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity were conducted to assess the suitability of the research data for PCA. In our study, we normalized the variables from the river water parameters dataset and conducted PCA to extract the most significant principal components, thereby diminishing the influence of less consequential variables. The components were then subjected to varimax rotation to simplify the interpretation of the results, transforming them into a set of orthogonal variables. Subsequently, we selected eigenvalues greater than 1 as the criteria for the new orthogonal variables. Drawing from established literature, factor loadings are categorized as "strong," "moderate," and "weak," corresponding to absolute loading values of greater than 0.75, between 0.75 and 0.50, and between 0.50 and 0.30, respectively (Wang et al., 2023).

3 Results

3.1 Chemical analysis of Beichuan River water

As can be seen from Table 1, the pH of the water body in the wet season ranges from 7.60 to 8.31, with an average of 8.08, while in the dry season it ranges from 7.82 to 8.32, averaging 8.17, indicating overall weakly alkaline water. The average value of TDS in wet season and dry season reached 224 mg/L and 236 mg/L respectively, exceeding the global average of 115 mg/L (Yang et al., 2021). This suggests that Beichuan River has a significant erosive effect on soluble salt rock. In the wet season and dry season, the order of the average concentration of cations in the water is: $Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}$, mainly Ca^{2+}, with an average mg equivalent percentage of 37.9%; The average concentration order of anions is: $HCO_3^->SO_4^{2-}>Cl^->NO_3^-$, in which the average mg equivalent percentage of HCO_3^- (68.7%) is higher than 50%, which is the main conducting anion.

3.2 Temporal and spatial variation characteristics of chemical components in Beichuan River

It can be seen from Figure 2 and Table 1 that spatially, from the upstream to the downstream of the study area, the concentration of hydrochemical components shows a gradual increase trend, mainly due to the increase of mineral dissolution with the increase of runoff

TABLE 1 Chemical composition statistics of Beichuan river water.

Section	Statistic	pH	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	NO_3^-	TDS
High flow	Min	7.60	1.43	5.27	33.5	2.90	5.60	27.2	103	2.37	147
	Max	8.31	2.82	41.0	63.8	22.2	42.0	119	198	17.6	358
	Average	8.08	1.93	15.3	49.0	10.1	17.3	45.8	150	8.30	224
	Standard deviation	0.175	0.458	10.8	7.77	5.17	12.4	20.5	28.8	4.37	63.3
	CV (%)	2.16	23.7	70.5	15.9	51.4	71.8	44.9	19.2	52.7	28.2
Low flow	Min	7.82	1.47	6.37	38.7	6.37	2.81	28.5	122	3.09	162
	Max	8.32	3.31	35.0	62.8	35.0	43.5	94.6	212	14.8	341
	Average	8.17	2.00	14.7	51.8	14.7	13.4	49.2	161	7.12	236
	Standard deviation	0.144	0.531	9.36	6.30	9.36	11.7	16.7	22.6	3.58	56.8
	CV (%)	1.77	26.6	63.7	12.2	63.7	86.8	34.0	14.0	50.2	24.1

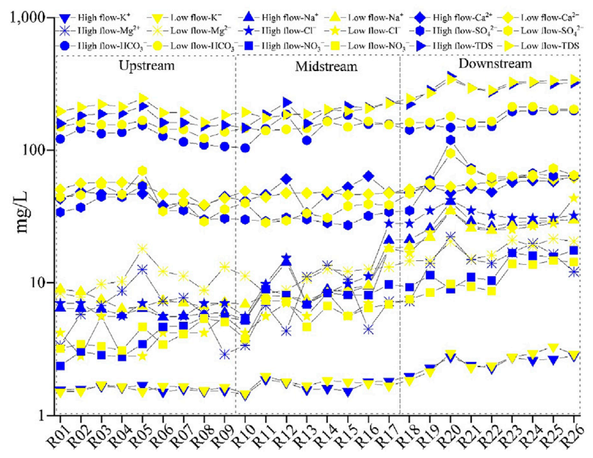

FIGURE 2
Spatial variation trend of main ion concentrations in surface water of Beichuan River.

distance, combined with the increase of human activities in the middle and lower reaches of the basin, domestic sewage, agricultural fertilizer and other pollutants continue to flow into the river, resulting in the increase of ion concentrations. Among them, the concentrations of Na^+, Mg^{2+}, SO_4^{2-}, Cl^- and NO_3^- changed greatly in space, and their coefficient of variation reached 70.5%, 51.4%, 44.9%, 71.8%, 52.7% in wet season and 63.7%, 63.7%, 34.0%, 86.8%, 50.2% in dry season, respectively. The disparity observed is primarily attributed to the significant variations in human activity levels across the upstream (where the predominant land use is forest and grassland, with minimal human intervention), midstream (impacted by agricultural activities and domestic wastewater), and downstream (entering Xining city, heavily influenced by the intensity of human activities, particularly domestic sewage) regions of the study area. The time variation of hydrochemical components shows that the average concentrations of Na^+, Cl^- and NO_3^- in the wet season are higher than those in the dry season, which is mainly due to the increase of rainfall in the wet season, and the strong surface runoff is more likely to cause rock salt dissolution, thus causing the increase of Na^+ and Cl^- concentrations (Ji et al., 2021). In addition, rainfall runoff will also bring more agricultural fertilizers to surface water, resulting in an increase in NO_3^- concentration (Jiang et al., 2022). The concentrations of K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^-, and TDS in dry season were slightly higher than those in wet season, indicating that rainfall had a certain dilution effect on these components.

3.3 Hydrochemical types in the study area

Piper trilinear chart can reveal the concentration characteristics and hydrochemical types of cations and anions in water (Ji et al., 2021). Figure 3 indicates that the sampling points are mainly distributed in the lower left corner of the cation diagram and anion diagram, indicating that $Ca^{2+}$and HCO_3^- are dominant in the water. During the wet season, the main hydrochemical type was HCO_3–Ca water (50.0%), followed by HCO_3–SO_4–Ca water (26.9%), HCO_3^-Ca·Mg water (11.5%). The concentrations of Ca^{2+}, Mg^{2+} and Na^++K^+ accounted for 64.0%, 19.7% and 16.4% of the total cations, respectively. The concentrations of HCO_3^-, SO_4^{2-} and Cl^- accounted for 64.7%, 24.0% and 11.3% of the total anions, respectively.

In the dry season, Ca^{2+}, HCO_3^- and SO_4^{2-} dominated. The hydrochemical types included HCO_3^-Ca water (38.5%), HCO_3·SO_4^-Ca water (23.1%), HCO_3–Ca·Mg water (19.2%), $HCO_3^-$$SO_4^-$Ca·Mg water (19.2%) and HCO_3–Ca·Mg water (19.2%). Ca^{2+}, $Mg^{2+}$and Na^++K^+ ions accounted for 61.2%, 24.8% and 14.0% of the total cations, respectively. HCO_3^-, SO_4^{2-} and Cl^- ions accounted for 66.8%, 24.9% and 8.3% of the total anions, respectively.

4 Disscusion

4.1 Water rock interaction

Gibbs diagram is shown in Figure 4, which is often used to infer the hydrogeochemical process of natural water (Zilberbrand et al., 2001). The diagram is divided into three endmembers, namely

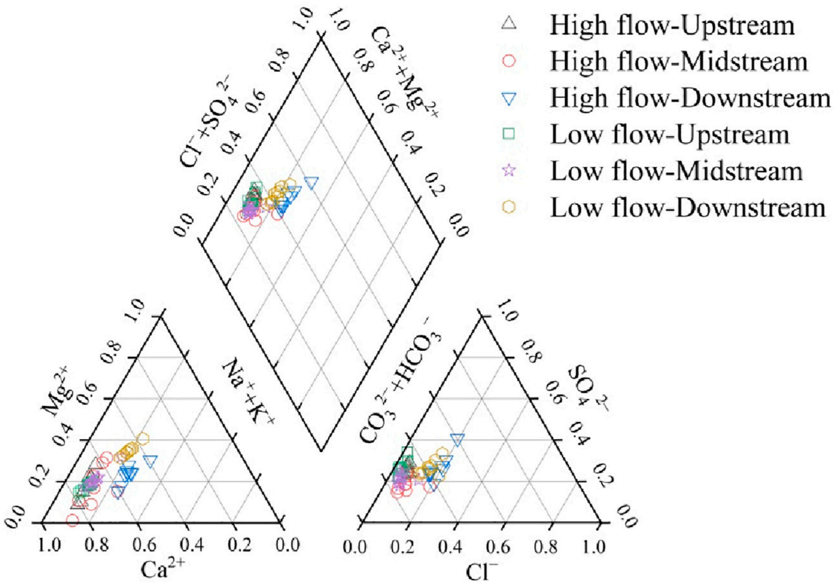

FIGURE 3
Piper diagram of main hydrochemical ions in surface water of Beichuan River.

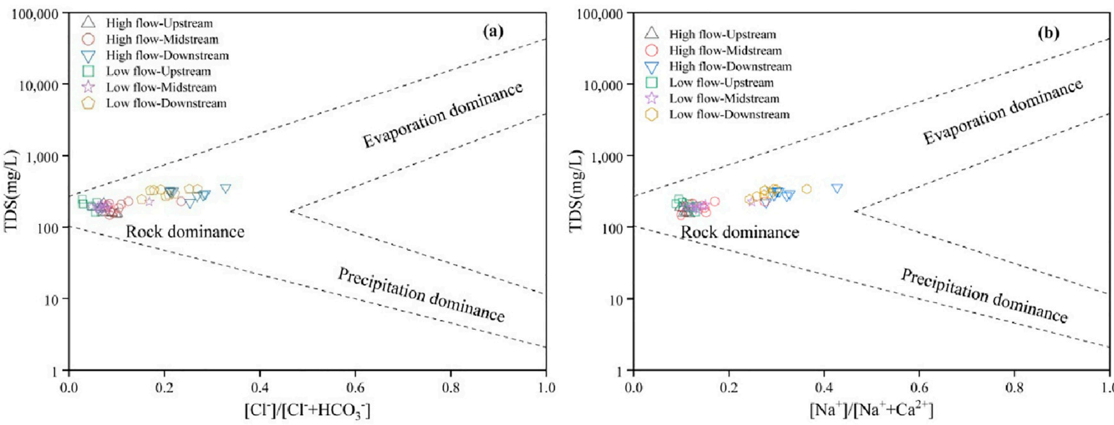

FIGURE 4
Gibbs diagram of Beichuan river surface water **(a)** TDS VS [Cl⁻]/[Cl⁻+ HCO_3-] and **(b)** TDS VS [Na^+]/[Na^++Ca^{2+}].

evaporation concentration, rock weathering and atmospheric precipitation. The control area of atmospheric precipitation has low total dissolved solids concentration (<10 mg/L), high [Na^+]/[Na^++Ca^{2+}] and Cl^-/[Cl^-+HCO_3^-] ratios, generally 0.5–1, which is distributed in the lower right corner of Gibbs diagram; The rock weathering zone is located in the middle of the left, and the TDS value is generally between 70 and 300 mg/L the ratio of [Na^+]/[Na^++Ca^{2+}] and [Cl^-]/[Cl^-+ HCO_3^-] is generally less than 0.5; The evaporation concentration control area is in the upper right corner of the figure, which exhibits a high TDS (>300 mg/L), and the ratio of [Na^+]/[Na^++Ca^{2+}] and [Cl^-]/[Cl^-+HCO_3^-] is also high (0.5~1). The Beichuan River basin water sample points plotted on Gibbs diagram. It can be seen from Figure 5 that most water sample points in the wet season and dry season fall in the rock weathering control area, indicating that the surface water chemistry in the Beichuan River basin is mainly controlled by rock weathering. Furthermore, a few water sample points in the middle and lower reaches of the wet season move into the evaporation concentration area, indicating that evaporation concentration also has a certain impact on the hydrochemistry of the area.

4.2 Source of water chemical composition

The ratio-end member diagram is usually used to reveal the source of ions produced by chemical weathering in the basin (Zhai et al., 2024). As [Ca^{2+}]/[Cl^-] and [Mg^{2+}]/[Na^+] are not affected by flow rate, dilution and evaporation (Pant et al., 2017), the

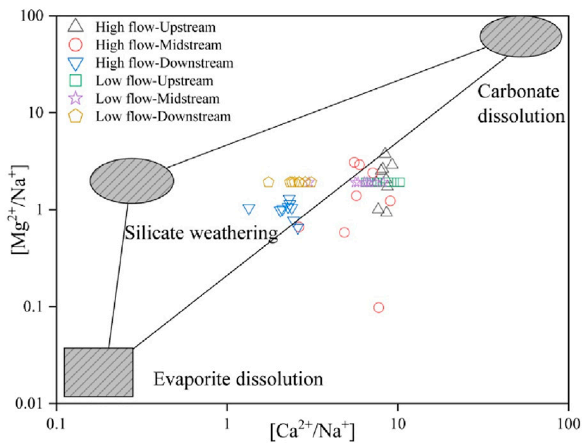

FIGURE 5
Relationship between $[Ca^{2+}]/[Na^{+}]$ and $[Mg^{2+}]/[Na^{+}]$.

hydrochemical origin can be revealed according to the relationship between Ca^{2+}/Na^{+} and Mg^{2+}/Na^{+}. Without the influence of human activities, Ca^{2+} and Mg^{2+} in the water environment are mainly from the weathering and dissolution of carbonate rocks and silicate rocks, Na^{+} and K^{+} are mainly from the weathering and dissolution of silicate rocks and rock salts, HCO_3^- is mainly from the weathering and dissolution of carbonate rocks and silicate rocks, and SO_4^{2-} and Cl^- are mainly from the dissolution of evaporite rocks and rock salts (Niu et al., 2022). It can be seen from Figure 5 that the Beichuan River water sample is located in the middle of the silicate rock and carbonate rock weathering zone. The upstream and middle reaches of the study area are closer to the weathering area of carbonate rocks, whereas the downstream water sample points are closer to the weathering area of silicate rocks, indicating that the ion source of the upstream and middle reaches of the Beichuan River basin is mainly the weathering and dissolution of carbonate rocks, and the main ion source of the downstream sites is the weathering and dissolution of silicate rocks.

In order to further identify the source of chemical components of surface water in the study area, the $[Na^{+}]/[Cl^{-}]$ map was used to identify the main sources of Na^{+} and Cl^{-}. In aquatic environment, Na^{+} mainly comes from the dissolution of salt rock and silicate rock, and the dissolution of salt rock will release the same proportion of Na^{+} and Cl^{-} (Fu et al., 2018). However, the concentration ratio of

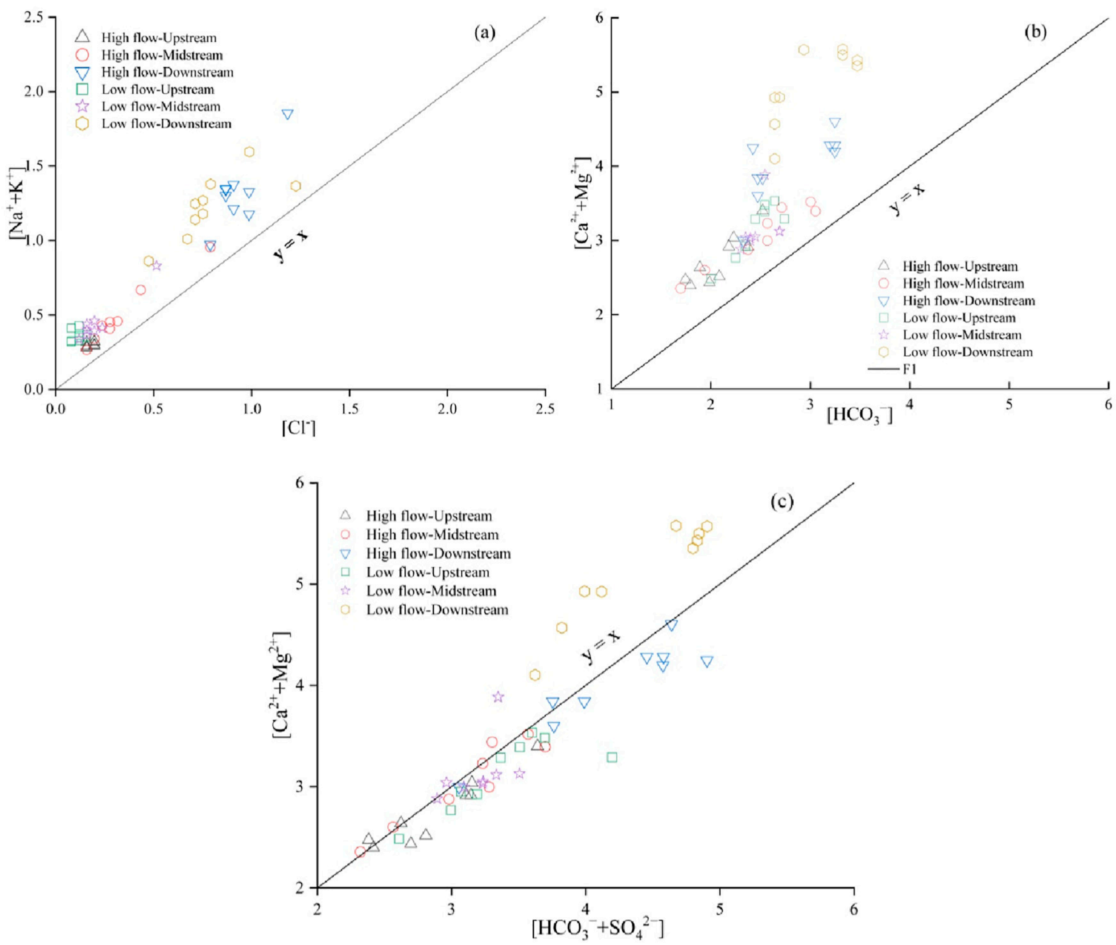

FIGURE 6
Relationship between Beichuan River $[Na^{+}]/[Cl^{-}]$ and Cl^{-} **(A)**, $[Ca^{2+}+Mg^{2+}]/[HCO_3^{-}]$ **(B)** and $[Ca^{2+}+Mg^{2+}]/[HCO_3^{-}+SO_4^{2-}]$ **(C)**.

$[Na^+]/[Cl^-]$ in the water samples of Beichuan River Basin during the wet season and dry season is between 1.17~1.74 and 1.05~4.71, respectively. Notably, the molar concentration of Na^+ in the downstream of the basin is significantly higher than that of Cl^-, which is far from the 1:1 line and close to the side of Na^+ (Figure 6A), indicating that Na^+ is not mainly from the dissolution of salt rocks, but may come from the dissolution of silicate rocks and the impact of human activities (sewage).

Ca^{2+} and Mg^{2+} in natural water mainly come from the dissolution of carbonate rock, silicate rock and evaporite, while HCO_3^- mainly comes from the dissolution of carbonate rock and silicate, which is less affected by human activities. When it mainly comes from the dissolution of carbonate rocks, the relationship between $[Ca^{2+} + Mg^{2+}]/[HCO_3^-]$ should be 1:1. When evaporite rocks are involved in the dissolution, the relationship between $[Ca^{2+} + Mg^{2+}]/[HCO_3^-+SO_4^{2-}]$ tends to be 1:1 (Wang et al., 2023). As shown in Figure 6B, the equivalent concentration ratio of $[Ca^{2+} + Mg^{2+}]/[HCO_3^-]$ at all water sample points in the wet season and dry season falls on the 1:1 line, indicating that Ca^{2+} and $mg^{2+}$are not only derived from the dissolution of carbonate rocks, but also from the dissolution of silicate rocks. After SO_4^{2-} is added (Figure 6C), most water samples fall near 1:1 of $[Ca^{2+} + Mg^{2+}]/[HCO_3^-+ SO_4^{2-}]$ in the upstream and midstream of wet season and dry season, indicating that evaporite is involved in dissolution. In addition, the excess SO_4^{2-} needs cations such as Na^+ and K^+ to balance, which further indicates the existence of silicate dissolution. In the lower reaches of the river during the dry season, most of the water samples are located above the 1:1 line, mainly because the groundwater is the primary supply source of the Beichuan River during the dry season, while the high concentration of Ca^{2+} and Mg^{2+} in the groundwater increases the concentration of Ca^{2+} and Mg^{2+}in the river.

4.3 Impact of human activities

Human activities also have a very important impact on the concentration of chemical components in water environment, such as domestic and industrial sewage discharge, agricultural activities and so on, which will affect the concentration of chemical components in water environment (Zhang et al., 2023). Generally, in areas with strong human activities, the concentrations of NO^{3-}, Cl^-, SO_4^{2-} and Na^+ in surface water will increase significantly (Zhang et al., 2020). Previous studies have shown that SO_4^{2-} in the water environment is mainly affected by industrial activities, while NO_3^-, Cl^- and Na^+ are affected by agricultural activities and domestic sewage (Zhang and Wang, 2020). Cl^- ion is often used as an indicator of the source of water pollution because it is not affected by the physical, chemical and biological effects of water in the process of water environment migration, and the ratio of Cl^- from different sources is different (Liu et al., 2006). Therefore, in this study, the ratio relationship between (NO_3^-/Cl^-) and $Cl^-$was used to determine the source of NO_3^- pollution in water (Yue et al., 2014). It can be seen from Figure 7A that the water sample points in the study area are mainly located near the two end elements of chemical fertilizer and sewage, indicating that NO_3^- in surface water is mainly from the input of chemical fertilizer and sewage. Among them, the land use in the upper reaches of the Beichuan River is mainly forest and grassland, and the land use in the middle reaches is mainly agricultural land and forest land. As shown in Figure 7A, the main source of NO_3^- in the upper and middle reaches of the Beichuan River is chemical fertilizer, and soil nitrogen also has a certain impact on nitrate in the water. However, in the lower reaches of Beichuan River, which flows through Xining city area, the discharge of domestic sewage from surrounding residents has an important impact on nitrate in water (Shu et al., 2024). As shown in Figure 7A, the downstream stations of Beichuan River are mainly located in the end element of sewage, indicating that sewage is the main source of nitrate pollution in the downstream waters of Beichuan River. In order to further identify the source of sulfate in water, the relationship between $[NO_3^-/Ca^{2+}]$ and $[SO_4^{2-}/Ca^{2+}]$ was used to further characterize the impact of human activities on surface water. Among them, mining activities have higher $[SO_4^{2-}/Ca^{2+}]$ value, while agricultural activities have higher $[NO_3^-/Ca^{2+}]$ value. As shown in Figure 7B, the Beichuan River has a high value of $[SO_4^{2-}/Ca^{2+}]$ and a low value of $[NO_3^-/Ca^{2+}]$ at the upstream site. Due to the low sulfate concentration in the Beichuan River (the average value in wet season and dry season is 45.8 mg/L and 49.2 mg/L respectively), the upstream river of the Beichuan River may be affected by mining activities in the basin (such as gypsum plant), but the impact is small. The midstream and downstream stations have higher $[NO_3^-/Ca^{2+}]$ values, which are more inclined to agricultural activities and sewage.

4.4 Hydrochemical control factors of Beichuan River

In this study, PCA employed to identify the pollution sources of Beichuan River in two hydrological periods. Nine water quality parameters (TDS, NO_3^-, K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-} and Cl^-) were selected for analysis. Prior to incorporating the data into the principal component analysis model, Kaiser Meyer Olkin and Barrett spherical tests were carried out on the research data. Results indicated that KMO values were 0.639 and 0.715 in the wet season and dry season, and the Barrett spherical test values were 484 ($p < 0.001$) and 513 ($p < 0.001$) respectively, indicating that the chemical data of Beichuan River water in the two hydrological periods met the requirements of principal component analysis. Based on an eigenvalue greater than 1, two main factors were identified in the two hydrological periods, which explained 89.9% and 91.8% of the information of all variables respectively (Table 2).

It can be seen from Table 2 that primary component 1 (PC1) in the wet season explains 76.7% of the total variable (Figure 7). The indicators showing strong positive correlation with PC1 include SO_4^{2-}, Na^+, TDS, Mg^{2+}, K^+ and Cl^-, and the indicator with medium positive correlation is NO_3^-. As the previous analysis shows, Na^+, Mg^{2+} and Cl^- in Beichuan River water are mainly from silicate dissolution, while SO_4^{2-} is mainly from evaporite dissolution. Previous studies have found that nitrate in the water environment mainly comes from sewage, manure, fertilizer, rainwater, soil nitrogen, etc., (Zhang X. et al., 2024; Ren et al., 2024). The above analysis also shows that the nitrate in Beichuan River water mainly comes from sewage and chemical fertilizer. Considering the moderate positive correlation between NO_3^- and PC1, the nitrate in PC1 may come from chemical fertilizer. Therefore, PC1 represents that the hydrochemistry of Beichuan River is affected by rock weathering and agricultural runoff. Primary component 2 (PC2) explained 13.2% of the total variable information. The indicators with strong positive correlation with

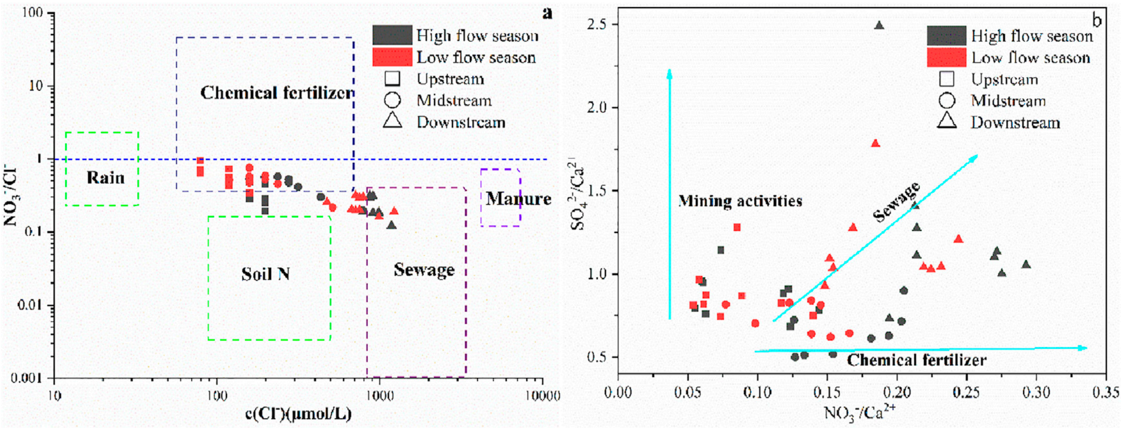

FIGURE 7
Relationship between [NO_3^-/Cl^-] and Cl^- **(A)** and [NO_3^-/Ca^{2+}] and [SO_4^{2-}/Ca^{2+}] **(B)** of Beichuan River.

TABLE 2 Principal component analysis of main ions in surface water of Beichuan River.

Parameters	Wet season		Dry season	
	PC1	PC2	PC1	PC2
SO_4^{2-}	0.945	0.081	0.482	0.756
Na^+	0.876	0.433	0.874	0.450
Mg^{2+}	0.859	0.249	0.874	0.450
Cl^-	0.840	0.425	0.888	0.393
K^+	0.820	0.529	0.850	0.452
TDS	0.820	0.565	0.720	0.688
Ca^{2+}	0.178	0.923	0.282	0.927
HCO_3^-	0.289	0.901	0.566	0.734
NO_3^-	0.538	0.734	0.882	0.338
characteristic value	6.91	1.19	7.09	1.19
Contribution rate (%)	76.7	13.2	80.2	11.6
Cumulative contribution rate (%)	76.7	89.9	80.2	91.8

PC2 were Ca^{2+}, HCO_3^- and NO_3^- and Na^+ and Cl^- also showed a moderate positive correlation with PC2. As the previous analysis shows, nitrate mainly comes from sewage and fertilizer. Since PC1 and PC2 are relatively independent, nitrate mainly comes from sewage. Previous studies have found that domestic sewage contains high concentrations of Na^+ and Cl^- (Zhang et al., 2020; Jiang et al., 2022). Therefore, PC2 represents that Beichuan River water chemistry is affected by domestic sewage.

In the dry season, PC1 explained 80.2% of the total variable (Figure 7). The indicators exhibited strong positive correlations with PC1 included Cl^-, NO_3^-, Na^+, Mg^{2+}, K^+ and TDS, and the indicator with medium positive correlation was HCO_3^-. The scarcity of rainfall in dry season makes it difficult for fertilizer in farmland to enter the river (Jiang et al., 2022). Consequently, PC1 represents that Beichuan River water chemistry is affected by domestic sewage. The indicators with strong positive correlation with PC2 were Ca^{2+}, HCO_3^- and SO_4^{2-}. Na^+, Mg^{2+}, K^+ and TDS also demonstrated moderate positive correlation with PC2. Therefore, PC2 represents that Beichuan River water chemistry is affected by rock weathering.

5 Conclusion

The comprehensive analysis of the Beichuan River's hydrochemical characteristics reveals a complex interaction between natural geological processes and human activities. The river's chemistry is predominantly controlled by rock weathering, with human activities, especially in the downstream areas, exerting a significant influence. Seasonal variations are largely driven by rainfall, which affects the dissolution of rock salts and the transport of agricultural pollutants. The wet season sees a greater impact from agricultural activities, while domestic sewage becomes more prominent in the dry season. The study's findings are crucial for understanding the hydrochemical dynamics in arid areas and have implications for the sustainable management of water resources. Future research should focus on the long-term effects of climate change and increasing human activities on the hydrochemical processes in this and similar arid environments.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

XJ: Data curation, Investigation, Software, Writing–original draft. WL: Data curation, Investigation, Methodology, Software, Writing–original draft. ZJ: Investigation, Validation, Writing–review and editing. TZ: Conceptualization, Methodology, Resources, Supervision, Validation, Writing–review and editing.

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Conflict of interest

Authors XJ and ZJ were employed by Shaanxi Land Construction Group Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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