Hydrochemical characteristics and water quality assessment of surface water in the northeast Tibetan Plateau of China

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ABSTRACT

The Tibetan Plateau is very important as it provides water resources for about 40% of the world's population and the runoff-yield area of the Yellow rivers. In this paper, the water quality in Xiahe County, located in the northeast Tibetan Plateau, was investigated. Six parameters (chloride, chemical oxygen demand, ammonia nitrogen, nitrate, fluoride, sulfate) were selected to assess the quality and health status of surface water in Xiahe County. The main types of hydrochemical in the surface water were considered to be Mg^{2+}-Ca^{2+}-HCO_3^--Cl^- and Mg^{2+}-Ca^{2+}-HCO_3^-. The cations and anions were mainly from weathering and dissolution of carbonate rock. Fuzzy comprehensive evaluation (FCE) results showed that the water quality in all 69 sampling sites was all class I. The integrated health status was higher than 0.95 and the health rate was 100%. Although ammonia nitrogen was recognized as the main contaminant, it had little effect on the entire body of water. Overall, the surface water qualities of most samples in Xiahe County were found to be in good condition.

Key words | fuzzy comprehensive evaluation, hydrochemical characteristics, surface water, Tibetan Plateau, water quality

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INTRODUCTION

The Tibetan Plateau is a water source for 40% of the world's population (Cao & Zhang 2015) and is called the 'Water Tower of Asia' because it feeds the Indus, Ganges, Brahmaputra, Yangtze and Yellow rivers (Huang *et al.* 2009; Zhou *et al.* 2013a, 2013b). Water, like in the 20th century, will become an important factor restricting the development of the global economy (Aly *et al.* 2016; Ren *et al.* 2016). Although climate warming has resulted in increased amounts of meltwater from the Tibetan Plateau, much of the water cannot be used. This reduces the availability of water for downstream applications, thus limiting the water consumption of these areas (Barnett *et al.* 2005; Gao *et al.* 2013; Cao & Zhang 2015). In recent years, studies have been carried out on the runoff (Chen *et al.* 2006) and precipitation of the plateau (Zhou *et al.* 2013a) and alpine lake water of the Tibetan Plateau (Song *et al.* 2014). However, most studies of Yangtze Estuary and Tibetan surface water quality have focused on major ions in saline lakes (Wu 2005).

Surface water is the most precious resource for people's daily life, irrigation and industry in the Tibetan Plateau pastoral area of Gansu Province. It consists of

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water that flows in the form of rivulets, springs, streams and rivers or that is collected to form ponds, lakes and sea discharge (Chidya *et al.* 2011). Surface water quality does not meet drinking water quality criteria. Severe drought and desertification at the end of the 20th century have created significant issues in water quality. Groundwater is now considered as one of the key methods to resolve the drinking water problem (Ding *et al.* 2007). Furthermore, the quality of the insufficient surface water is susceptible to decline. Firstly, surface water can be contaminated by anthropogenic activities (Venkateswaran & Deepa 2015; Sun *et al.* 2016) from non-point sources and point sources. The non-point-source pollutants are washed from the earth's surface by storm runoff and enter water bodies of their own accord (Cheng *et al.* 2007), whereas the point-source pollutants are directly released into water bodies in man-made pipes (Zampella *et al.* 2007; Gyawali *et al.* 2013). Secondly, agricultural activities degrade water quality directly or indirectly because of the ever-increasing mass of fertilizers, pesticides and dairy manure in croplands (Yu *et al.* 2013; Giri & Qiu 2016). As a result, surface water quality is a matter of serious concern, being vital to human health, for quality of crops (and thus grains) may be affected by the soil and contaminated environment (Zhang *et al.* 2012; Voyslavov *et al.* 2013). Surface water quality and availability have deteriorated due to ongoing increase in population, industrialization, and anthropogenic activities (Erturk *et al.* 2010; Cao & Zhang 2015; Effendi 2016). Increase in water pollution affects not only water quality but also endangers human health, ecological balance, economic development, and social prosperity (Voyslavov *et al.* 2013). Consequently, water quality assessment is important for the protection of people's health, agriculture, industry, recreation, tourism and ecosystems (Dinka *et al.* 2015).

Currently, studies on hydrochemical characteristics and water quality assessment of water are mainly concentrated on river, estuary wetland, and lake areas (Cui & Li 2014a, 2014b). However, surface water study in the Tibetan Plateau pastoral area has been neglected. Xiahe County not only belongs to the northeast Tibetan Plateau and the National Nature Reserve of the Three Rivers Source but also the runoff-yield area of the Yellow River. This paper took Xiahe County as an example to study the hydrochemical characteristics and quality of surface water of the northeast Tibetan Plateau pastoral area. In this study, 69 surface water sampling sites were selected to analyze the hydrochemical characteristics and water quality of surface water in the northeast Tibetan Plateau of China. The fuzzy comprehensive evaluation (FCE) method, field research, multivariate statistical methods, and the Piper diagram were applied to analyze the hydrochemical characteristics and quality of the surface water. Based on the above analysis, the main objectives of this study were: (1) to reveal the correlation between surface water samples of anions and cations; (2) to analyze the hydrochemical type of surface water; (3) to assess the quality of surface water in Xiahe County.

STUDY AREA

Xiahe County (101°54′–103°25′E, 34°32′–35°34′N) is located in the southern part of Gansu Province and the northeast edge of the Qinghai–Tibetan Plateau, China (Li *et al.* 2011). It is a pure animal husbandry county and the most important grazing land of Gannan Tibetan Autonomous Prefecture, Gansu Province. The population, composed primarily of herdsmen, exceeds 80,000, who live in an area of 6,274 square kilometres (Li *et al.* 2015). The average annual temperature is 2.6 °C with the highest 28.9 °C and the lowest −24.6 °C. The average annual precipitation is approximately 516 mm, and is concentrated in the months of July and August (Hou *et al.* 2013). Many abundant storm water tributaries, the snow-capped mountains and lakes constitute an integral water conservation system of the Yellow River, as a 'reservoir' (Wang *et al.* 2012). The Daxia and Tao rivers, which flow through Xiahe County, also belong to the Yellow River 'reservoir'.

MATERIALS AND METHODS

Water Sampling

Sixty-nine surface water samples were collected from Xiahe County in the northeast Tibetan Plateau pastoral area, on 15 July 2012. The spatial distribution map of surface water sampling sites in Xiahe County is shown in Figure 1. Water samples were collected with plastic bottles (500 ml). Each

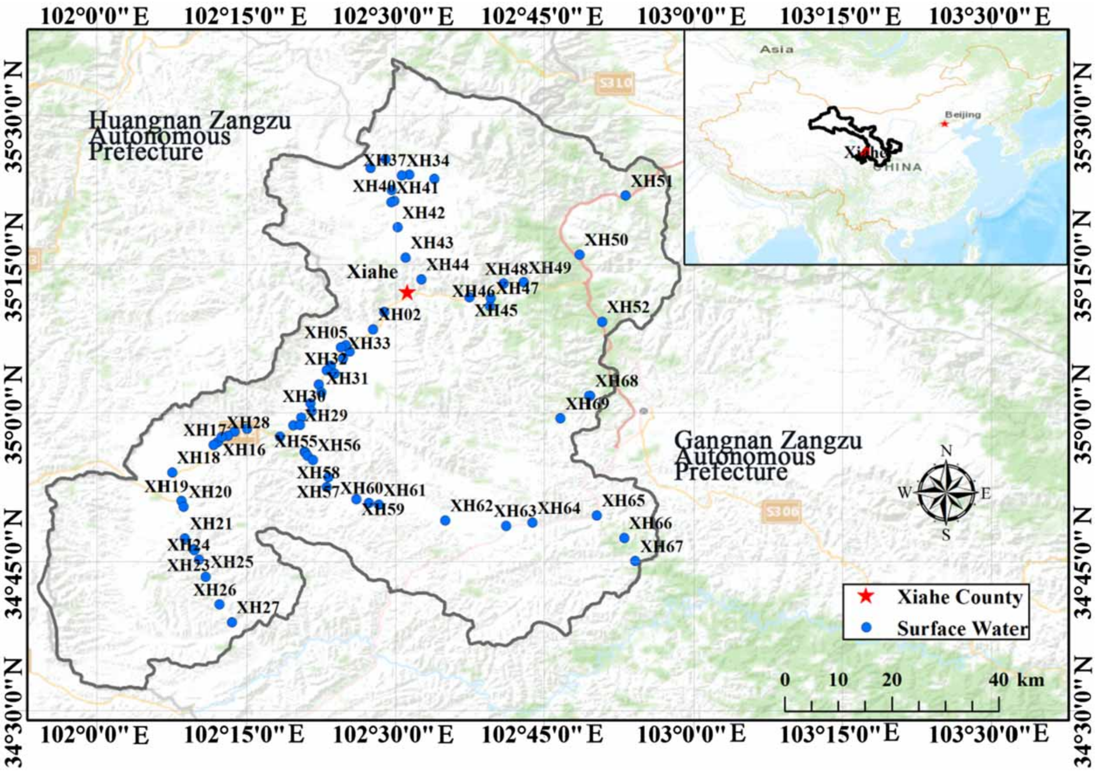

Figure 1 | Distribution map of surface water sampling sites in Xiahe County.

sample had three replicates and a detention time of 1 min. Water samples were taken at a depth of approximately 30 cm below the water surface. The water was stored at a temperature below 4 °C after bottling in the laboratory.

Analytical techniques

The water quality parameters monitored for each sample included the physical properties of water samples, including turbidity, pH, and electric conductivity (EC). The chemical composition was Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, HCO_3^-. The toxicological indicators of F^-, NO_3^-. EC and pH were analyzed immediately in the field, and other parameters were analyzed in the laboratory. These samples were filtered through a 0.45 μm membrane filter before analysis. Analytical methods and parameters, which were based on the methods outlined in the Chinese National Quality Standards for Drinking Water (GB/T 5749-2006 and GB/T 5750-2006), are summarized in Table 1.

Assessment methods of surface water

The FCE is a quantitative scientific evaluation method and has been widely applied in many fields, such as environmental (Liu *et al.* 2010), agriculture (Cheng & Tao 2010), and engineering (Piplani & Wetjens 2007). FCE is used to determine changes in water quality upstream/downstream of sites, i.e, the extent of contaminants from anthropogenic activities. The advantages and disadvantages of water quality can be observed visually. The principal procedure of FCE includes establishing the evaluation factor set

$$U = \{U_1, U_2, U_3, \ldots U_n\} \tag{1}$$

and grading level set

$$V = \{V_1, V_2, V_3, \ldots V_m\} \tag{2}$$

of evaluated objects. This membership function with each category is expressed as follows (Bi *et al.* 2015; Xie *et al.* 2017).

Table 1 | Analytical methods used for the analysis of surface water

Quality parameter	**Symbol of method used**	
Turbidity	Turbidity	Turbidity meter
pH	pH	pH meter
Electrical conductivity	EC	Electrical conductivity meter
Sodium	Na^+	Inductively coupled plasma optical emission spectroscopy (ICP-OES)
Calcium	Ca^{2+}	
Potassium	K^+	
Magnesium	Mg^{2+}	
Ammonium	NH_4^+	Nesslers reagent photometry
Chloride	Cl^-	$AgNO_3$ titration
Sulfate	SO_4^{2-}	Barium chromate indirect atomic absorption spectrophotometry
Bicarbonate	HCO_3^-	Acid–base titration
Chemical oxygen demand	COD	Potassium dichromate method
Fluorine	F^-	Fluoride ion electrode
Nitrate nitrogen	NO_3^-	Ion selective spectrometry

The membership function of level 1 is:

$$r_{i1} = \begin{cases} 1 & (c_i \le s_{i1}) \\ (s_{i2} - c_i) \big/ (s_{i2} - s_{i1}) & (s_{i1} < c_i < s_{i2}) \\ 0 & (c_i \ge s_{i1}) \end{cases} \tag{3}$$

The membership function of level j is:

$$r_{ij} = \begin{cases} 1 - {}^{s_{ij} - c_i}\!/\!{}_{s_{ij} - s_{i(j-1)}} & (s_{i(j-1)} < c_i < s_{ij}) \\ (s_{i(j+1)} - c_i) \big/ (s_{i(j+1)} - s_{ij}) & (s_{ij} < c_i < s_{i(j+1)}) \\ 0 & (c_i \le s_{i(j-1)} \text{ or } c_i \ge s_{i(j+1)}) \end{cases} \tag{4}$$

The membership function of level m is:

$$r_{im} = \begin{cases} 0 & (c_i \le s_{i(m-1)}) \\ 1 - {}^{s_{im} - c_i}\!/\!{}_{s_{im} - s_{i(m-1)}} & (s_{i(m-1)} < c_i < s_{im}) \\ 1 & (c_i \ge s_{im}) \end{cases} \tag{5}$$

where r_{i1}, r_{ij}, and r_{im} are is the fuzzy memberships of indicator i to classes 1, j, and m, respectively; c_i is the monitoring value; s_{ij} is the allowable value of the water quality indicator.

The fuzzy evaluation matrix R is the comprehensive survey of the index of safety evaluation of surface water and will have i rows and j lines, that is to say $R = [r_{ij}]$ (Zhou *et al.* 2013a, 2013b):

$$R = [r_{ij}] = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1j} \\ r_{21} & r_{22} & \cdots & r_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ r_{i1} & r_{i2} & \cdots & r_{ij} \end{bmatrix} \tag{6}$$

Then determine a weighting factor W and the assessment index weighting factor is determined as in Equation (7):

$$W = (W_1, W_2, W_3, W_4, W_5) \left(\sum_{i=1}^{5} W_i = 1, W_i \ge 0 \right) \tag{7}$$

where W is the weighting factor; W_1, W_2, W_3, W_4, and W_5 are the weights for the evaluation parameters.

$$B = W \times R \tag{8}$$

where B is the FCE matrix of membership of each water quality class. B is normalized using Equation (9) and the final FCE matrix B' is obtained as shown in Equation (10). A water sample is classified to the class with the maximized membership (Zhang *et al.* 2012):

$$b_i = \frac{b_j}{\sum_{j=1}^{5} b_j} \tag{9}$$

$$B' = (b_1, b_2, b_3, b_4, b_5) \tag{10}$$

The chloride, COD, ammonia nitrogen, nitrate, fluoride, and sulfate were used as assessment parameters to establish an evaluation factor set U ($n = 6$) that depended on 69 surface water sample sites from Xiahe County. An evaluation criteria set V ($m = 5$) was also determined (Table 2) and water quality classification according to the Environmental Quality Standards for Surface Water of China (GB3838-2002).

RESULTS AND DISCUSSION

Hydrochemical characteristics of surface water

Descriptive statistics

Descriptive statistics, which include the maximum, minimum, variation coefficient (VC), range, arithmetic mean, variance, skewness and standard deviation (SD), were used for the hydrochemical characteristics of surface water as shown in Table 3. Factors with skewness values lower than 2, including K^+, Mg^{2+}, Cl^-, pH, COD, and EC, showed normal distributions. Na^+, F^-, and SO_4^{2-} were large and especially for Ca^{2+}, showed heterogeneous concentration distributions. It may be due to the excessively high concentration in some samples (XH17, XH49). For Mg^{2+}, Cl^-, pH, and EC the VCs were lower than 0.5, while those of K^+, Na^+, Ca^{2+}, SO_4^{2-} and NO_3^- were higher than 0.5 (range from 0.5 to 0.9). Low VCs may result from a natural source and high VCs may be impacted by anthropogenic activities (Bu *et al.* 2016). HCO_3^- ranged from 24.62 to 237.86 mg L^{-1}, Cl^- ranged from 11.70 to 45.73 mg L^{-1}, and sulfate ranged from 6.02 to 50.80 mg L^{-1} (with mean of 13.78 mg L^{-1}). Therefore the major anions of the surface water were mainly dominated by HCO_3^-. The HCO_3^- in the surface water was from carbonate weathering and dissolution by carbonic acid (Gautam *et al.* 2015). Mg^{2+} ranged from 5.43 to 40.64 mg L^{-1}, Ca^{2+} ranged from 2.79 to 74.39 mg L^{-1}, sodium ranged from 2.91 to 48.52 mg L^{-1}, and K^+ ranged from 0.87 to 6.20 mg L^{-1} (with mean of 2.01 mg L^{-1}). Thus the major cations were mainly dominated by Ca^{2+} and Mg^{2+}. Na^+ and K^+ derived from the dissolution of silicate minerals. SO_4^{2-} mainly came from $CaSO_4$ and $MgSO_4$ through evaporation of saline mineral solution.

Table 2 | Standard of quality classification for surface water

Parameter/mg L^{-1}	I	II	III	IV	V
Chloride	250	250	250	250	250
	15	15	20	30	40
Ammonia nitrogen	0.15	0.5	1.0	1.5	2.0
Nitrate	10	10	20	20	25
Fluoride	1.0	1.0	1.0	1.5	>1.5
Sulfate	250	250	250	250	250

The coefficient variation of turbidity was the largest, which could be due to effluents from agricultural return flow (Dinka *et al.* 2015). It did not meet the WHO (1996) guideline for drinking water which was set at 5 NTU (Hoko 2005). EC ranged from 130 to 726 μS cm^{-1} (with a mean of 596 μS cm^{-1}) and 24.6% samples exceeded the desirable limit of 500 μS cm^{-1}. Geochemical processes along with evaporation, silicate weathering, sulphate reduction, oxidation process and ion exchange were the main contributors to the large variation in EC (Mohapatra *et al.* 2009). However, in the study area, the variation of EC could be primarily due to anthropogenic activities and agricultural activities.

According to the WHO (2009), the standard pH values for drinking water range from 6.5 to 8.5 and that of irrigation water from 6.5 to 8.4 (El-Sayed & Salem 2015). Most of the surface water samples were found to have pH values ranging from 7.16 to 8.65 which indicated that they were suitable for drinking and irrigation.

Piper diagram

The Piper diagram is useful for geochemical evaluation and is a graphical presentation of the major ions to quickly determine the hydrochemical facies of the surface water in the study area (Srinivasamoorthy *et al.* 2014; Venkateswaran & Deepa 2015; Ebrahimi *et al.* 2016). However, the main weakness of the Piper diagram is that it shows the chemical character of surface water based on the relative concentration of its constituents rather than the absolute concentrations. As shown in Figure 2, the major cation and anion concentrations were demonstrated in the bottom left and right triangles,

Table 3 | Descriptive statistics of surface water samples in Xiahe County

Parameter	**Range**	**Min**	**Max**	**Mean**	**SD**	**VC**	**Variance**	**Skewness**
K^+ / mg L^{-1}	5.34	0.87	6.20	2.01	1.04	0.52	1.08	1.78
Ca^{2+}/ mg L^{-1}	71.6	2.80	74.4	13.1	8.51	0.65	72.4	5.53
Na^+/ mg L^{-1}	45.6	2.90	48.5	7.69	6.89	0.90	47.4	3.82
Mg^{2+}/ mg L^{-1}	35.2	5.43	40.6	14.1	6.04	0.43	36.1	1.92
F^-/ mg L^{-1}	0.30	0.06	0.36	0.13	0.06	0.48	0.004	2.05
Cl^-/ mg L^{-1}	34	11.7	45.7	23.8	6.62	0.28	43.8	0.36
SO_4^{2-}/ mg L^{-1}	44.8	6.02	50.8	13.8	9.97	0.72	99.4	2.21
NO_3^-/ mg L^{-1}	6.76	0.46	7.22	1.50	1.05	0.71	1.10	3.34
HCO_3^-/ mg L^{-1}	213	24.6	238	73.6	36.8	0.50	1,351	2.2
pH	1.49	7.16	8.65	8.09	0.29	0.04	0.09	−1.07
COD/ mg L^{-1}	16.6	2.08	18.7	6.43	3.72	0.58	13.8	1.43
EC / μS cm^{-1}	596	130	726	353	111	0.32	1,230	0.7
Turbidity / NTU	752	0.17	752	70.6	162	2.3	2631	3.34

respectively. The dispersion of HCO_3^- dominated the waters, while the majority of samples were mainly concentrated in the Mg^{2+} and Ca^{2+} fields, accounting for more than 70% of the cations. This suggested that the hydrochemicals in the surface water were dominated mainly by Mg^{2+}-Ca^{2+}-HCO_3^--Cl^- with Mg^{2+}-Ca^{2+}-HCO_3^- being secondary. This was consistent with the hydrochemical types of Qinghai Lake Basin (Cui & Li 2014a, 2014b) and Bukan basin, in the northwest of Iran

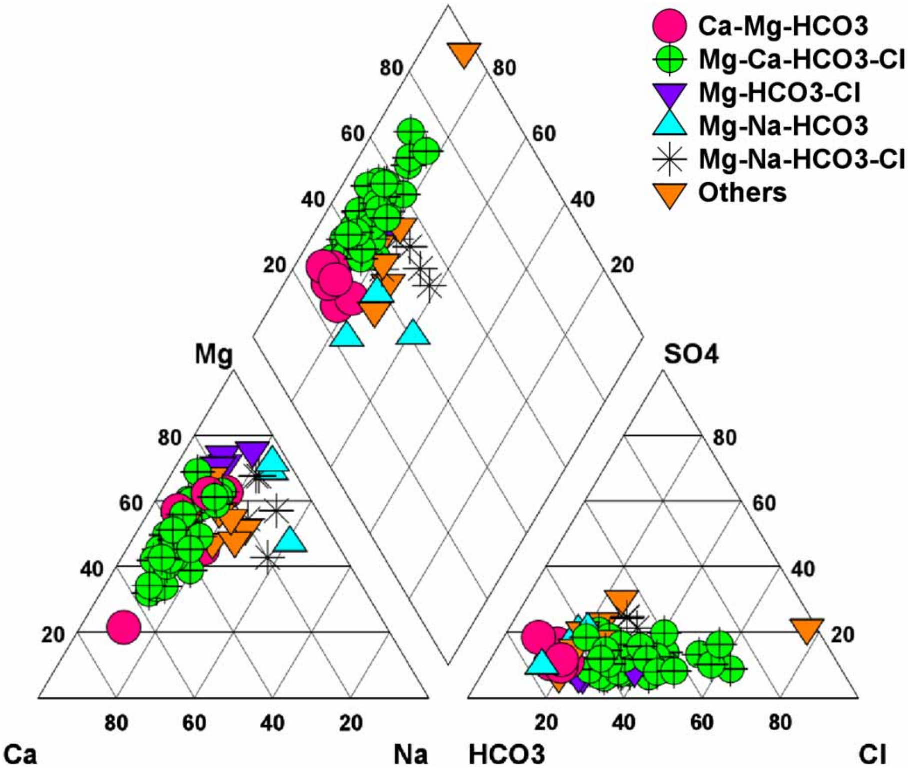

Figure 2 | Piper diagram showing the hydrochemical compositions of surface water in Xiahe County.

(Pazand & Hezarkhani 2012). The anions and cations in the surface water could mainly come from the weathering and dissolution of carbonate rock, or be associated with anthropogenic activities (Chidya *et al.* 2011). In addition, Li *et al.* (2007) found that Ca^{2+} and HCO_3^- accounted for 59% of the total ions in rainfall and this suggested that precipitation affects their concentration since heavy precipitation can wash crystallized aerosols out of the atmosphere.

Spearman's correlation coefficient

Spearman's correlation coefficient is a moment correlation coefficient performed on the ranks of the data rather than the raw data (Puth *et al.* 2015). The analyzed parameters are shown in Table 4. A significant correlation was found between pH on the one hand and concentrations of K^+, turbidity, and F^- on the other. A significant positive correlation was established between concentrations of K^+, Ca^{2+}, Na^+, Mg^{2+}, HCO_3^-, and NO_3^- and the sulfate content of the surface water. Concerning the principal ions, a correlation was also found between Mg^{2+}, Na^+, and HCO_3^-. The content of F^- and K^+ was increased with the decrease in pH. At the same time, the concentrations of Ca^{2+}, Mg^{2+}, and Na^+ were increased with increasing concentrations of HCO_3^- and showed a significant positive correlation ($r = 0.41, 0.75, 0.64$, respectively). The significant positive correlation suggests that the leading cations such as Mg^{2+}, Ca^{2+}, Na^+ and K^+ were from weathering of different rocks. For example, Mg^{2+} and Ca^{2+} were supplied by the silicates and carbonates (Xiao *et al.* 2015), Na^+ and K^+ by the weathering of silicates (Xiao *et al.* 2015). In general, HCO_3^- values were found to be the highest in samples from all seasons and sites indicating that weathering of rock plays a major role (Gautam *et al.* 2015). Ion exchange may be one of the other important processes influencing water geochemistry in semiarid/arid areas (Xiao *et al.* 2015).

Water quality assessment

Spatial analysis of surface water quality

In order to investigate the surface water quality of Xiahe County, maps of pH, turbidity, ammonia nitrogen, fluoride, sulfate, and chloride were interpolated by using ArcGIS 10.2. As shown in Figure 3, the pH values are almost stable around 8, which may be due to high concentrations of NH_4^+ and Ca^{2+} present in rainfall (Li *et al.* 2016). The complex patterns of pH reflect the spatial heterogeneity of the geology (Chang 2008). Turbidity was often related to flow rate and an indirect measure of water clarity. Higher flows may decrease water clarity owing to the increased amount of suspended material. There is a high concentration of ammonia in downstream sites and low concentrations in the central and

Table 4 | Correlation matrices of hydrochemical parameters of surface water in Xiahe County

	K^+	Ca^{2+}	Na^+	Mg^{2+}	SO_4^{2-}	Cl^-	HCO_3^-	NO_3^-	F^-	pH	Turbidity	COD	EC
K^+	1												
Ca^{2+}	0.04	1											
Na^+	0.73**	−0.02	1										
Mg^{2+}	0.38**	−0.17	0.62**	1									
SO_4^{2-}	0.64**	0.33**	0.81**	0.53**	1								
Cl^-	0.07	−0.07	0.16	0.13	0.03	1							
HCO_3^-	0.47**	0.41**	0.64**	0.75**	0.69**	−0.16	1						
NO_3^-	0.64**	−0.14	0.85**	0.50**	0.74**	0.18	0.40**	1					
F^-	0.65**	0.15	0.53**	0.34**	0.47**	0.10	0.46**	0.49**	1				
pH	−0.33**	−0.12	−0.11	−0.09	−0.20	−0.06	−0.11	−0.10	−0.33**	1			
Turbidity	0.31*	−0.09	−0.06	0.03	0.02	0.13	−0.09	0.07	0.49**	−0.32**	1		
COD	0.32**	−0.09	0.19	0.03	0.13	0.08	−0.02	0.17	0.17	−0.12	−0.01	1	
EC	0.53**	−0.02	0.67**	0.80**	0.62**	0.08	0.72**	0.51**	0.41**	−0.16	¯0.01	0.19	1

*Significant at $P < 0.05$, **significant at $P < 0.01$, $N = 69$.

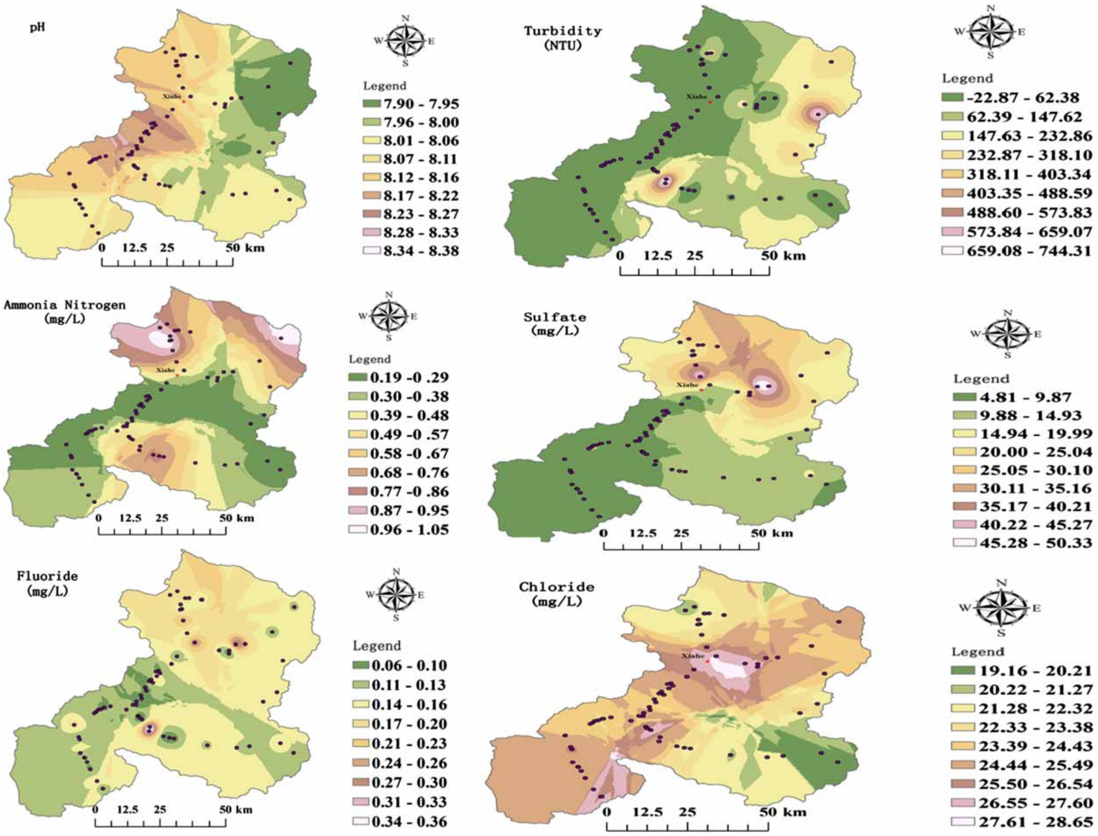

Figure 3 | Spatial distribution of surface water about pH, turbidity, ammonia nitrogen, sulfate, fluoride, and chloride in Xiahe County.

upstream sites. The fluoride and sulfate showed similar patterns – high in the upper eastern part and low in the lower western part of Xiahe County. The concentration of chloride was relatively high in the entire region, which may indicate that Cl^- was initiated from the agricultural activity in the region, accumulated in the subsurface over time and eventually washed down toward the water body (Baram *et al.* 2014).

High concentrations in downstream sites from their point-source loads are mainly derived from human activities and the nutrient inputs from agriculture which involves the extensive use of fertilizers (Kilonzo *et al.* 2014). Detailed spatial distribution of water quality may supply significant information for ecological water demand and thus the environmental safety of the Plateau pastoral area.

Fuzzy comprehensive evaluation

The FCE results are shown in Table 5. We found that the surface water quality was all class I, and the integrated health status exceeded 0.95, which means that water quality for most samples was good and suitable for drinking and irrigation. Some of the concentrations of ammonia nitrogen were between class I and class III, with the exception of six samples (XH34, XH36, XH39, XH40, XH59, XH60) which were class IV and three samples (XH41, XH42, XH51) which exceeded class V. XH34 and XH51 were located in Ganjia and Quao townships indicating that human activities could have a direct effect on water quality. The water quality of XH41 and XH42 could be affected by agricultural activities since these two sites are surrounded by villages and croplands. XH59 and XH60 were located in depopulated zone. XH36, XH39, XH40 and other sites were mainly located in a suburban regions which focused on pasture husbandry. Animals drink directly from the surface water, and may have contributed to the increasing concentrations of the parameters. Thus, ammonia nitrogen was found to be the main pollutant from the following sources: (a) biodegradable waste, animal waste and plant

Table 5 | Results of fuzzy comprehensive evaluation

Sample	b_1	b_2	b_3	b_4	b_5	WQ	FCE
XH1	0.863	0.105	0.032	0	0	I	0.966
XH2	0.887	0.038	0.077	0	0	I	0.964
XH3	0.979	0.021	0	0	0	I	0.996
XH4	0.960	0.040	0	0	0	I	0.992
XH5	0.989	0.011	0	0	0	I	0.998
XH6	0.978	0.022	0	0	0	I	0.996
XH7	0.985	0.168	0	0	0	I	0.997
XH8	0.974	0.026	0	0	0	I	0.995
XH9	0.990	0.010	0	0	0	I	0.998
XH10	0.978	0.022	0	0	0	I	0.996
XH11	0.972	0.028	0	0	0	I	0.998
XH12	0.968	0.032	0	0	0	I	0.994
XH13	0.914	0.058	0.028	0	0	I	0.977
XH14	0.981	0.019	0	0	0	I	0.996
XH15	0.997	0.003	0	0	0	I	0.999
XH16	0.870	0.097	0.033	0	0	I	0.967
XH17	0.981	0.019	0	0	0	I	0.996
XH18	0.977	0.023	0	0	0	I	0.995
XH19	0.984	0.016	0	0	0	I	0.997
XH20	0.949	0.051	0	0	0	I	0.990
XH21	0.910	0.090	0	0	0	I	0.982
XH22	0.977	0.023	0	0	0	I	0.995
XH23	0.968	0.032	0	0	0	I	0.994
XH24	0.985	0.015	0	0	0	I	0.997
XH25	0.961	0.039	0	0	0	I	0.992
XH26	0.968	0.032	0	0	0	I	0.994
XH27	0.913	0.061	0.026	0	0	I	0.977
XH28	0.972	0.028	0	0	0	I	0.994
XH29	0.986	0.014	0	0	0	I	0.997
XH30	0.975	0.025	0	0	0	I	0.995
XH31	0.972	0.028	0	0	0	I	0.994
XH32	0.981	0.019	0	0	0	I	0.996
XH33	1.000	0	0	0	0	I	1.000
XH34	0.942	0	0.035	0.023	0	I	0.972
XH35	0.948	0.052	0	0	0	I	0.990
XH36	0.961	0	0.009	0.028	0	I	0.978
XH37	0.993	0.007	0	0	0	I	0.999
XH38	0.985	0.015	0	0	0	I	0.997
XH39	0.938	0	0.053	0.009	0	I	0.973
XH40	0.951	0	0.023	0.026	0	I	0.975
XH41	0.974	0	0	0.022	0.004	I	0.984
XH42	0.967	0	0	0.030	0.003	I	0.980
XH43	0.886	0.114	0	0	0	I	0.977
XH44	0.980	0.020	0	0	0	I	0.996
XH45	0.981	0.019	0	0	0	I	0.996
XH46	0.972	0.028	0	0	0	I	0.994
XH47	0.981	0.019	0	0	0	I	0.996
XH48	0.874	0.033	0.093	0	0	I	0.956
XH49	1.000	0	0	0	0	I	1.000
XH50	1.000	0	0	0	0	I	1.000
XH51	0.984	0	0	0.007	0.009	I	0.989
XH52	0.935	0	0.062	0.003	0	I	0.973
XH53	0.932	0.010	0.058	0	0	I	0.975
XH54	0.927	0.023	0.050	0	0	I	0.975
XH55	0.935	0.003	0.062	0	0	I	0.975
XH56	0.936	0.001	0.063	0	0	I	0.975
XH57	0.985	0.015	0	0	0	I	0.997
XH58	1.000	0	0	0	0	I	1.000
XH59	0.959	0	0.010	0.031	0	I	0.977
XH60	0.949	0	0.030	0.021	0	I	0.975
XH61	0.917	0.053	0.030	0	0	I	0.977
XH62	0.974	0.026	0	0	0	I	0.997
XH63	0.930	0.070	0	0	0	I	0.986
XH64	0.993	0.007	0	0	0	I	0.999
XH65	0.997	0.003	0	0	0	I	0.999
XH66	0.997	0.003	0	0	0	I	0.999
XH67	0.955	0.045	0	0	0	I	0.991
XH68	0.997	0.003	0	0	0	I	0.999
XH69	0.993	0.007	0	0	0	I	0.999

WQ: water quality.

residues from agricultural waste production and increasing industrial activities in the Plateau pastoral area (Liu *et al.* 2014); (b) local herders' and tourists' garbage and waste (Cong *et al.* 2009; Hu *et al.* 2015); (c) cattle breeding and fertilizer applications that could release a mass of NH_3, which is converted to aerosol NH_4^+ or directly scavenged by rainwater (Li *et al.* 2016). Additionally, excessive use of fertilizers, manure and pesticides is likely to be harmful to water quality, although they are used for improved production and protection of crops (Darko *et al.* 2008; Liu *et al.* 2014).

To ensure improved quality of surface water there needs to be attention on the following items: (a) the residues and dung generated by plants and animals should be recycled; (b) domestic waste arising from tourism and daily life activities of local herdsmen should be separated, recovered and treated properly; (c) relevant government departments should work on improving awareness about environmental protection aims to reduce the impact on drinking water for the northeast pastoral population.

CONCLUSIONS

The 69 surface water samples were used to analyze the hydrochemical characteristics and quality of the surface water of Xiahe County. This research mainly found the following. (1) The hydrochemistry type in the surface water of Xiahe County was dominated mainly by Mg^{2+}-Ca^{2+}-HCO_3^--Cl^- and Mg^{2+}-Ca^{2+}-HCO_3^-. (2) FCE showed that the surface water quality of nearly all samples was class I, and the integrated health status reached more than 0.95. This indicates that the water quality of most samples was in the good to excellent category and the water was suitable for irrigation directly but not for drinking unless treated appropriately. (3) Ammonia nitrogen was found to be the main pollutant. This document may serve as a guide for future researchers to evaluate the surface water conditions in the Tibetan Plateau pastoral area of China.

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