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Research on the development law of karst fissures and groundwater characteristic in Xintian County

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Abstract. The natural hydrology and geological conditions of Xintian County was investigated, the development law of regional karst fissures was studied, the groundwater was collected and tested through a large-scale collection of groundwater to obtain the change law of chemical characteristics and water quality characteristics of groundwater, and the water quality evaluation was carried out for the regional karst groundwater in this paper. The results show that, the whole area is dominated by carbonate rock distribution areas, and the distribution of water systems is relatively developed. The strata are distributed from the Lower Paleozoic Cambrian to the Cenozoic Quaternary, and contain multiple first-order folds. The regional karst dynamic action is strong, and many tunnels or caves of different scales were shown, which are conducive to the enrichment of groundwater. Karst groundwater is neutral and alkaline water, the water is clear and transparent with good taste, and meets the national drinking water hygiene standards. The content of toxic trace elements and fluoride in the water source is generally lower than the limit value specified by the national standard and the accumulated toxic heavy metals is never found. The overall water quality is of good quality and suitable for the development and utilization of various purposes.
Keywords: karst fissure; underground water; water quality; water chemical characteristics

1. Introduction

As an important source of the origin of life, water resources have always received special attention from people and are the key issues to contemporary resource, environment and development (Zhao 2021, 2022, Li 2021). Many countries and regions in the world are facing the problem of water shortage, and China is also a water-scarce country. As an important source of drinking water, groundwater has always played an important role in water resources. According to statistics, 1/4 of the population of the world relies on karst water as the main source of water (Ahmed *et al*. 2020, Bae 2020, Nataša *et al*. 2021, Francesco *et al*. 2021, Farooq *et al*. 2021, Simon *et al*. 2021). Groundwater is the main or only water source for people in arid areas in the north and karst rocky mountain areas in the southwest.

Karst water refers to the groundwater that occurs in the dissolution fissures and caves of soluble rock formations (Andrea *et al*. 2021, Liu and Long 2022, Long *et al*. 2022). Karst water has strong water content, but the water content is extremely uneven. Usually shallow karst fissures are well developed, while deep ones are weakly developed due to in-situ stress, so the water-rich water of the aquifer also has strong and weak zoning. Karst water also has obvious anisotropy in hydraulic connection (Liu *et al*. 2007, Zhang *et al*. 2018, Wang *et al*. 2020, Guillaume *et al*. 2020, Simon *et al*. 2020, Peter and Grzegorz 2021, Jaqueline *et al*. 2022). The water contains trace elements needed by the human body, as a special resource, it is increasingly favored by people and has been highly valued by governments at all levels, especially those in the impoverished rocky and mountain area (Ma 2016, 2021, Zhang *et al*. 2020, Maryam *et al*. 2020, An *et al*. 2022, Ali *et al*. 2022).

The Xintian County, which in Hunan Province has the obviously characteristics of rocky and mountain area (Su *et al*. 2017, Xia *et al*. 2017). However, the water content and occurrence conditions of groundwater in the region, the characteristics of hydrogeological structure and the genetic mechanism of groundwater are still unclear. On the basis of summarizing the existing data, the karst development law of groundwater in Xintian County, the change law of hydro-chemical characteristics and water quality evaluation are studied and analyzed in this paper, which provided important guiding significance for the distribution characteristics, water quality evaluation and sustainable exploitation of groundwater in this area.

2. Natural geological conditions and karst development law

2.1 Natural hydrological conditions

Xintian County is located in the southern of Hunan

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Fig. 1 Distribution of surface water system in Xintian County

Province and southeast of Yongzhou City. The eastern of Xintian County is adjacent to Guiyang County in Chenzhou City, Jiahe County in the south, Ningyuan County in the west, and Qiyang County in the north. The county covers an area of 1003.89 km2, of which the carbonate rock distribution area is 996.44 km2, accounting for 99.25% of the total area of the county.

According to the hydrological survey data, Xintian County is located in the Xintian River Basin, belonging to the Xiangjiang River system, and there is no large river in the territory. The whole territory includes rivers, streams, ditches, and streams, with a total of 114, which are irregularly dendritic. Among them, there are 26 main streams with a length of more than 5 km, 47 main streams with a length of 1-5 km, and the others are gullies with a length less than 1 km. There is only one first-class tributary of Xiangjiang River-Chongling River (the main stream in the territory is 4 km long), 3 second-class tributaries (Xintian River, Shangzhuang River, Qianjiadong River), and 4 third-class tributaries (Ridong River, Rixi River, Shiyang River, and Shanxiadong River), 65 fourth and fifth-level tributaries. In addition, mountain (flat) ponds and reservoirs are scattered among them, and the water area accounts for 1.68% of the total area of the county. The distribution of the water system in Xintian County is shown in Fig. 1.

2.2 Geological conditions

According to the geological survey, in addition to the absence of the Lower Devonian, Permian, Triassic, and Tertiary, the strata in the area are distributed from the Lower Paleozoic Cambrian to the Cenozoic Quaternary. The Lower Paleozoic Middle-Upper Cambrian-Silurian is mainly a set of shallow metamorphic marine clastic and argillaceous sediments, with a thickness of 3564-5600 m, which is mainly distributed in the middle and low mountains in the north. The Devonian and Carboniferous of the Upper Paleozoic are dominated by neritic carbonate deposits, followed by terrestrial and littoral clastic deposits, of which the Devonian has a larger facies change, which is mainly distributed in the eastern, southeastern hills and the western low mountain. The Mesozoic Jurassic and Cretaceous are all continental red clastic deposits, which are only exposed in a small area in the west, and are in unconformity contact with the underlying strata. The Quaternary of the Cenozoic is dominated by residual slope deposits, followed by alluvial deposits. Residual slope

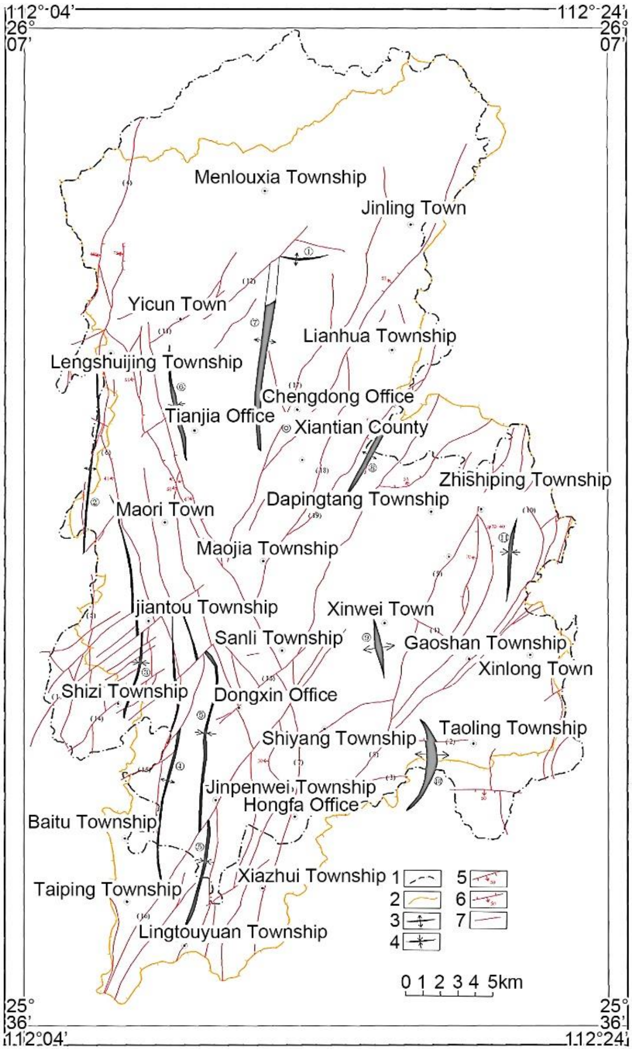

Fig. 2 Tectonic outline of Xintian County (1. Boundary of Xintian County, 2. River Basin Boundary of Xintian County, 3. Anticline axis (the hollow is the inferred axis), 4. Syncline, 5. Normal fault, 6. Reverse fault, 7. Character unknown fault)

deposits are thin and widely distributed. Most of the carbonate rocks are weathered red clay, and the clastic rocks are mostly tan, gray-yellow, and gravel clay. Alluvial deposits are mainly scattered on both sides of the river valley. In addition, small pieces of magmatic rocks (eruptions) are seen sporadically outcropping in the west.

Located between the Nanling anticline and the north of Yangmingshan-Tashan anticline, Xintian is a large complex syncline with many subordinate folds developed in the complex syncline. Among these secondary folds, except for the east-west Qingpiyuan anticline-tightly closed fold, the rest of the regions are transitional folds extending in a nearly north-south direction. The outline of the geological structure of Xintian County is shown in Fig. 2.

2.3 Development law of regional Karst

Xintian County is located between Yangming Mountain and Jiuyi Mountain in southern Hunan. The terrain is roughly high in the northwest, low in the southeast, and inclined to the southeast. It is an irregular elongated basin that is long from north to south and narrow from east to west. The individual forms of surface karst in Xintian County mainly include stone buds, stone forests, karst hills, karst trenches (troughs), karst caves, karst fissures, depressions, sinkholes (sinkholes), karst shafts (karst wells), karst skylights, and karst pool, etc.

A total of 10 underground rivers were found in Xintian County, with a total length of more than 20km, an average distribution density of $0.028km/km^2$, a total discharge of $1.85m^3/s$, and an annual discharge of 0.58×10^9 m^3. According to the statistics of 23 karst springs in Xintian County, the total excretion volume is $1.059m^3/s$, and the annual excretion volume is 0.33×10^9 m^3. Among them, 4 rising springs, 19 falling springs, 90% of the big springs are distributed in the Fenglin Valley and Fenglin Plain, and 75% of the big springs are related to the fault-affected zone. In this work, among the 51 drilling holes, the karst caves was found in the 8 drilling holes, accounting for 15.7% of the total number of drilling holes. The smallest cave is 0.2m, the largest is 11.9m, and most of them are less than 1m, all filled with mud. The distribution elevation of karst caves is 137.90-225.2m and most of them are 180m.

2.4 Superficial karst zone

The epikarst zone in the surface part is the strongly karstified vadose zone or shallow water-saturated zone in the karst mountain area. Located at the intersection of the lithosphere, the atmosphere, the biosphere and the hydrosphere, the karst dynamic effect is strong and the environment is sensitive to changes, which has an extremely important impact on the ecological construction and economic development of the karst area. The springs in the epikarst belt of this basin are mainly exposed in the Daguanling area in the west, and are mostly found in the limestone and dolomitic limestone in the lower member of the Upper Devonian tin mine Formation (D3x1) and the Shetianqiao Formation (D3s). At the exit of the superficial karst spring, the thickness of the overlying Quaternary clay and rubble are 2-5 m, with local thickness is 10 m, and the underlying limestone dissolution fissures are developed. According to the incomplete statistics, there are a total of 23 epikarst springs, most of which have been developed and utilized.

Carbonate karstification is a reversible process in the three-phase equilibrium system of carbonate rock, water and carbon dioxide, in which the entry or escape of CO_2 plays a key role in the reflection of the system. The development of Karst is restricted by four basic conditions of stratum lithology, geological structure, groundwater dynamic conditions, and water erosiveness. In the most favorable geological structures, micro-forms such as dissolved crevices or fractures are formed at first. With time going on, these micro-forms gradually expand to form tunnels or karst caves of different scales. In general, water flow is enriched first under the conditions of favorable structural (especially fracture) and gradually forms karst caves. The lithology of different rock groups affects the

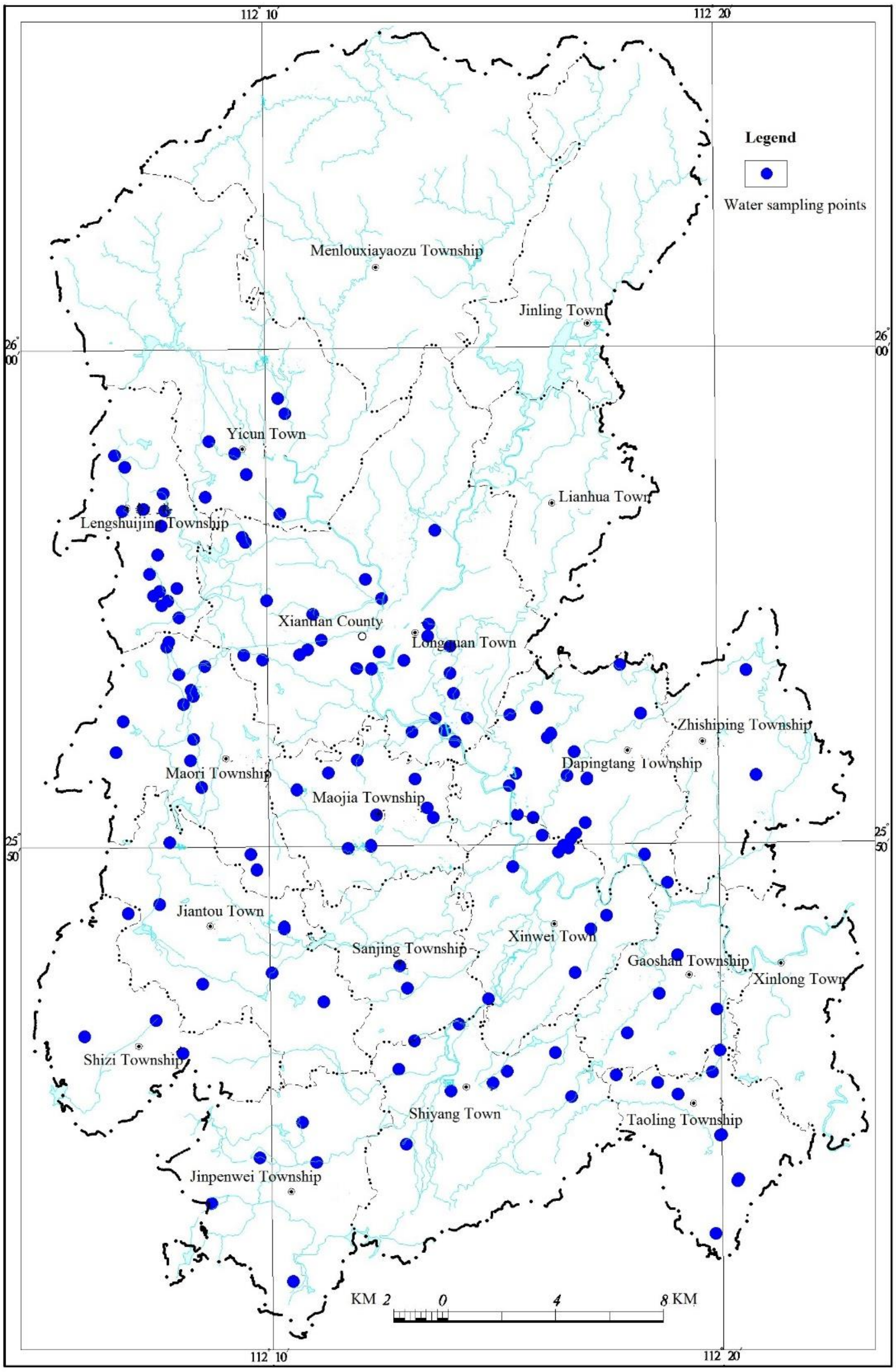

Fig.3 Distribution of water chemistry sampling points in Xintian County

degree of karst development through the main diagenetic minerals and trace diagenetic minerals and structure of the rock, and the external dynamic conditions such as climate work through internal factors. The main factors affecting karst development in this area are lithology and structure. When the lithology conditions are the same, the structure becomes the main controlling factor which affecting the karst development.

The influence of structure on karst development is mainly manifested in that the direction of karst development is controlled by structure. The carbonate strata in the area have strong folds and developed fractures, resulting in multiple groups of joint fissures, especially the layered and longitudinal fissures, which have created good conditions for karst development channels. These channels are controlled by the strike of the strata, the direction of fissure development, and the tectonic line. When the lithology of the strata is the same, the karst development degree of the strata with gentle occurrence is higher, and the karst development degree of the stratum with steep occurrence is

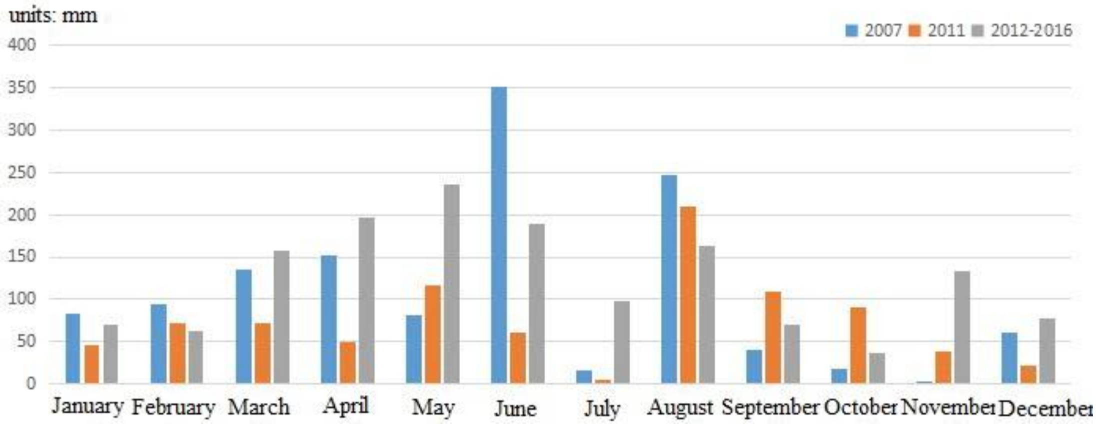

Fig. 4 Comparison of monthly rainfall in Xintian County in 2007, 2011 and 2012-2016

Table 1 Statistical of characteristic values of groundwater chemical components in Xintian County in 2007, 2011 and 2012-2016

Eigenvalues	mean value (mg/L)			maximum value (mg/L)			Minimum value (mg/L)			standard deviation (mg/L)		Coefficient of variation (%)	
Year	2007	2011	2012-2016	2007	2011	2012-2016	2007	2011	2012-2016	2011	2012-2016	2011	2012-2016
HB	240.27	269.70	1368.82	191.63	512.71	507.76	312.28	170.59	69.00	66.02	265.87	24.5%	211.64%
TDS	246.70	339.64	196.69	324.82	639.00	743.74	185.15	77.00	236.92	114.92	370.33	33.8%	222.63%
K^+	1.00	1.36	0.78	2.26	18.20	3.76	0.30	0.02	0.29	1.74	1.63	127.4%	237.60%
Na^+	1.39	5.40	12.7	2.45	119.51	190.00	0.14	0.15	0.28	13.13	39.00	243.3%	1313.89%
Ca^{2+}	90.30	88.43	40.24	70.00	167.67	167.67	129.99	46.67	12.4	21.84	83.33	24.7%	229.78%
Mg^{2+}	3.55	11.86	6.90	14.78	64.46	25.81	0.00	0.69	1.95	8.30	13.15	70.0%	235.86%
Cl^-	9.33	12.37	3.73	17.22	134.01	134.01	1.01	0.43	1.60	19.76	23.00	159.7%	702.57%
SO_4^{2-}	7.35	26.87	8.44	40.87	230.00	230.00	0.00	2.00	5.00	25.72	36.01	95.7%	652.20%
HCO_3^-	267.07	286.72	176.63	349.54	504.98	564.00	215.10	166.88	218.76	65.39	326.86	22.8%	222.10%
Free CO_2	2.64	11.87	11.2	6.50	79.20	61.6	0.00	0.00	61.60	13.78	20.40	116.1%	238.27%

lower. The structures such as joints and fissures in the surface layer are the precursors of karst development, which provide good basic conditions for the penetration and dissolution of precipitation into the surface rock mass.

3. Change laws of chemical characteristics of groundwater

The groundwater in the area is mostly room temperature water, the water temperature is relatively constant and is less affected by temperature changes. The annual temperature is maintained at 11 to 25 °C, and the annual change range is 1.5 to 6.2 °C. It is mostly colorless, odorless and transparent in appearance. However, the water quality at the outlet of some underground rivers is temporarily turbid during the rainy season.

A total of 173 sets of groundwater samples were collected in Xintian County, including 135 sets before the year of 2011 and 30 sets from the year of 2012 to 2016, and 24 sets of groundwater test data were collected. Most of the samples before the year of 2011 were collected at the end of the high-water period in 2011-the flat-water period. According to the investigation of groundwater exposure and occurrence conditions, the water chemistry was sampled and tested. The distribution of sampling points is shown in Fig. 3.

The changing laws of the water chemistry of groundwater in the area were preliminary analyzed and be drawn to determine by comparing and analyzing the test data of 135 samples in this survey with the test data obtained by the Karst Geology Research Institute of the Chinese Academy of Geological Sciences in 2007, and combing with the natural and human factors of the water cycle in Xintian County.

Atmospheric precipitation is an important source of groundwater recharge in Xintian County, and it is also one of the main factors affecting the chemical characteristics of groundwater. According to the analysis of the precipitation frequency in the area, it can be seen that the rainfall in 2007 was 1277.8 mm, and the equivalent frequency was 73.3% of the dry year, while the rainfall in 2011 was 892.0 mm, and

Table 2 Overview of representative groundwater source points in Xintian County

Hole number	Location	Aquifer formation	Water volume (m^3/d)	Remark
ZK12-4	Tuqiaoping Village Dapingtang Township	D_3x^1	102.5	development point of drilling and lifting
ZK10-4	Lijia, Meijia Village, Gaoshan Township	D_3x^1	485.6	development point of drilling and lifting
KF1	Hejia well, Jiantou Town	C_1y^1	1600	demonstration point for development and utilization of underground rivers
ZK9-3	Chen Weixin Village, Jinpenwei Township	C_1y^1	311	development and demonstration point of drilling and lifting
ZK12-1	Huangqing Village, Lengshui well Township	C_1y^1	394.4	development point of drilling and lifting
1445	Dali County Village, Longquan Town	D_3s	535.7	rural safe water supply project
ZK9-4	Yuantou Village, Longquan Town	C_1y^1	500	development point of drilling and lifting
ZK12-11 (collect)	Maojia Village, Maojia Village	D_3x^1	252	rural safe water supply project
ZK13-10 (collect)	Sunyuping Village, Sanjing Township	D_2q	401	rural safe water supply project
KF3 (9017)	Tangping Village, Sanjing Township	C_1y^1	200	demonstration point for development and utilization of underground rivers
KF2 (9012)	Cross Country Scar Rock	C_1d^1	1600	development and utilization demonstration of site Karst pool
9282	Xiao'e Well in Shiyang Town	D_3x^1	770.7	Karst big spring
ZK10-3	Taoling Township Zhou Family	D_2q	120	development and demonstration point of drilling and lifting
ZK11-2	Xinwei Town Huolitang Drilling	D_3x^1	482	development and demonstration point of drilling and lifting
1488	Longjingtang Village, Ping Township, Zhi City	$C_{2+3}ht$	274.8	Karst spring
ZK3 (year of 2016)	Fanxitou Village, Xinxu Town	D_3s	583.3	drilling and lifting
ZK4 (year of 2016)	Daotang Village, Xinwei Town	D_2q	436.59	drilling and lifting

the equivalent frequency was 100.0% of the extremely dry year. Under the condition that the permeability coefficient does not change much, the natural recharge of groundwater in the area is 35.1% less. The average rainfall from 2012 to 2016 was 1492.36 mm, and the groundwater recharge increased with an equivalent frequency of 11.6-60.0% and an average of 36.00%.

It can be seen from Table 1 that the average content of the main chemical components of groundwater in the area in 2007 and 2011 was changed greatly. Except for the slight decrease in Ca^{2+} concentration, all others increased significantly. Among them, the changing percentages of the free CO_2, Na^+, SO_4^{2-}, and Mg^{2+} reached 349%, 288%, 266%, and 234%, respectively. It can be seen from the standard deviation of the main anions and cations, the deviations of HCO_3^- and SO_4^{2-} of anions are 65.39 and 25.73, respectively, which ranking the top two, while the K^+ and Mg^{2+} of cations are ranked last with 1.74 and 8.30. It can be seen from the coefficient of variation that the Na^+ and K^+ in cations and Cl^- in anions all exceed 100%, while Ca^{2+} is the smallest at 24.7%. Since the year of 2012, due to the increasing rainfall and abundant groundwater supply, the ion content of chemical components is generally reduced such as K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, free CO_2, HB, and TDS except for Na^+.

In general, when the atmospheric precipitation in Xintian County decreased more, the chemical composition of groundwater changed greatly. The precipitation in dry years was less than the evaporation, the concentration of most components in surface water increased, and the groundwater also showed that the component concentration fluctuates in the opposite direction with the atmospheric precipitation, and it changes in a positive direction when the recharge increases. From the perspective of a deeper layer, the shallow karst groundwater in the area is greatly affected by seasons and precipitation, that reflecting the complex recharge sources of shallow karst groundwater in the area and the relatively large dynamic changes of hydro-chemical components.

4. Results and discussion

Most area of Xintian County is karst, and the groundwater resources are abundant but unevenly distributed, which is mainly concentrated in the karst development area in the southwest. The spatial and temporal distribution of surface water resources is extremely uneven, floods are occurred in high water seasons, and droughts occurred in dry seasons. Xintian County is densely populated and economically under-developed, which makes it a national-level poverty-stricken county. Therefore, the groundwater plays an important role in social and economic development. According to the

Table 3 Evaluation score of individual component (GB/T 14848-93)

Categories	I categories	II categories	III categories	IV categories	V categories
Fi	0	1	3	6	10

Table 4 Classification of groundwater quality levels (GB/T 14848-93)

Categories	excellent	better	good	poor	very poor
F	<0.80	0.80~<2.50	2.50~<4.25	4.25~<7.20	>7.20

statistical analysis of the water quality analysis results of 17 representative groundwater sources in Xintian County, the general situation of each water source can be obtained as shown in Table 2.

4.1 Characteristics of water quality

According to the National Standard of the People's Republic of China "Quality Standard for Groundwater" (GB/T 14848-93) implemented in 1994, groundwater quality is divided into five categories.

I categories, mainly reflects the natural low background content of groundwater chemical components. Suitable for various purposes.

II categories, mainly reflects the natural background content of groundwater chemical components. Suitable for various purposes.

III categories, based on the benchmarks of human health. Mainly suitable for centralized drinking water sources and industrial and agricultural water.

IV categories, based on agricultural and industrial water requirements. Except for agricultural and some industrial water, it can be used as drinking water after proper treatment.

V categories, not suitable for drinking. Other water can be selected according to the purpose of use.

Each individual item is classified and scored according to the classification index of groundwater quality, and the evaluation score of each individual component is as shown in Table 3, which is used as the basic value to classify the groundwater quality.

The evaluation method is the comprehensive index method, and the calculation formula is as shown below.

$$F = \sqrt{\frac{\overline{F}^2 + F^2_{\max}}{2}} \quad (1)$$

$$\overline{F} = \frac{1}{n}\sum_{i=1}^{n} F_i \quad (2)$$

where, $\overline{F}$ is the average value of each single component evaluation score Fi. F_{max} is the maximum value in the evaluation score Fi of each single component. n is the number of items.

According to the comprehensive evaluation score F, the groundwater quality level is classified in Table 4.

According to the sampling analysis project, the evaluation factors of groundwater quality are 18 items, which include pH, total hardness, total dissolved solids, sulfate, chloride, iron, manganese, copper, zinc, nitrate, nitrite, ammonia nitrogen, fluorine, mercury, arsenic, cadmium, chromium (hexavalent), and lead as shown in Table 5.

According to the monitoring and analysis of the water quality, it can be seen that the water bodies of the 16 water sources are clear and transparent, colorless, free of peculiar smell, no suspended foreign matter, good taste, chromaticity and turbidity are low, and the various physical and sensory properties meet the requirements of the drinking water hygiene standards (GB 5749-85). In the general chemical index of water, the pH is between 7.22 and 7.83, with an average value of 7.38, which is neutral and alkaline water. The temperature of the water source is generally 17.5 to 22.0 °C, with an average of 19.5 °C, which is cold water. The water quality status of representative groundwater source points in Xintian County is relatively good. Among the 16 representative water source points participating in the evaluation, 14 of them have excellent or good groundwater quality, accounting for 87.5% of the total.

The total dissolved solids are between 204 and 639 mg/L, with an average value of 304.26 mg/L, and the total hardness is between 170.59 and 381.45 mg/L, with an average value of 253.53 mg/L, all of which are soft water with low mineralization. The concentrations of chlorides, sulfates and metal ions such as iron, manganese, copper, and zinc are also generally low, which are lower than the limit value of the sanitary standard for drinking water (GB 5749-85) and the better water standard value of groundwater quality standard (GB/T 14848-93), and the general chemical indicators of the water source are in line with the standards of GB 5749-85 and GB/T 14848-93. The content of toxic trace elements and fluoride in the water source is generally lower than the limit value stipulated by the national standard, and there is no obvious phenomenon of exceeding the standard. Among them, arsenic, mercury, cadmium, hexavalent chromium and lead and other accumulated toxic substances were almost not detected, and they were generally at a very low background level, which met the requirements of the national standard. Cyanide contaminated by human activities is nearly not be detected. Most of the nitrite content is lower than the standard value of water with good quality standard of groundwater. The water sources in the area almost maintain their natural background status, and generally have not suffered obvious pollution, and the water quality nearly meets the requirements of the national standard. However, a few water sources are polluted in some areas, such as the sewage ditches and waste dumping sites in towns and villages, which is characterized by the increase in the concentration of nitrate pollutants. For example, the nitrite concentration in Yuantou Village Longquan Town (ZK9-4) reaches 0.04 mg/L, which exceeds the standard. Holes ZK1 and ZK2 drilled in 2016 have fluorides exceeding 0.52 mg/L and 1.23 mg/L respectively. Mercury in ZK12-6 hole exceeds the standard by 0.009 mg/L, fluoride in ZK13-4 hole exceeds the standard by 0.2 mg/L, cadmium exceeds 0.015 mg/L, lead exceeds 0.09 mg/L, manganese exceeds 0.57 mg/L, and oxygen consumption exceeds 1.20 mg /L.

Table 5 Groundwater quality classification index (GB/T 14848-93)

Serial number	Item Standard Value Category	I categories	II categories	III categories	IV categories	V categories
1	pH	6.5～8.5	6.5～8.5	6.5～8.5	5.5～6.5 8.5～9.0	<5.5 >9.0
2	total hardness (as CaCO3)	≤150	≤300	≤450	≤550	>550
3	total dissolved solids	≤300	≤500	≤1000	≤2000	>2000
4	sulfate	≤50	≤150	≤250	≤350	>350
5	chloride	≤50	≤150	≤250	≤350	>350
6	iron (Fe)	≤0.1	≤0.2	≤0.3	≤1.5	>1.5
7	manganese (Mn)	≤0.05	≤0.05	≤0.1	≤1.0	>1.0
8	copper (Cu)	≤0.01	≤0.05	≤1.0	≤1.5	>1.5
9	zinc (Zn)	≤0.05	≤0.5	≤1.0	≤5.0	>5.0
10	nitrate (as N)	≤2.0	≤5.0	≤20	≤30	>30
11	nitrate (as N)	≤0.001	≤0.01	≤0.02	≤0.1	>0.1
12	ammonia nitrogen (as N)	≤0.02	≤0.02	≤0.2	≤0.5	>0.5
13	fluorine (F)	≤1.0	≤1.0	≤1.0	≤2.0	>2.0
14	mercury (Hg)	≤0.00005	≤0.0005	≤0.001	≤0.001	>0.001
15	arsenic (As)	≤0.005	≤0.01	≤0.05	≤0.05	>0.05
16	cadmium (Cd)	≤0.0001	≤0.001	≤0.01	≤0.01	>0.01
17	chromium (hexavalent)	≤0.005	≤0.01	≤0.05	≤0.01	>0.01
18	lead (Pb)	≤0.005	≤0.01	≤0.05	≤0.1	>0.1

Note: The pH value in the standard value is dimensionless, and the other units are mg/L

Table 6 Pollution assessment results of representative groundwater source points in Xintian County

Hole number	Location	Aquifer formation	Evaluation results	Comprehensive rating value	Excessive factor
ZK12-4	Tuqiaoping Village Dapingtang Township	D_3x^1	better	2.16	
ZK10-4	Lijia, Meijia Village, Gaoshan Township	D_3x^1	better	2.19	
KF1	Hejia well, Jiantou Town	C_1y^1	better	2.14	
ZK9-3	Chen Weixin Village, Jinpenwei Township	C_1y^1	better	2.16	
ZK12-1	Huangqing Village, Lengshui well Township	C_1y^1	better	2.16	
1445	Dali County Village, Longquan Town	D_3s	better	2.13	
ZK9-4	Yuantou Village, Longquan Town	C_1y^1	poor	4.27	nitrite
ZK12-11	Maojia Village, Maojia Village	D_3x^1	better	2.24	
ZK13-10	Sunyuping Village, Sanjing Township	D_2q	better	2.17	
KF3 (9017)	Tangping Village, Sanjing Township	C_1y^1	better	2.13	
KF2 (9012)	Cross Country Scar Rock	C_1d^1	better	2.14	
9282	Xiao'e Well in Shiyang Town	D_3x^1	better	2.14	
ZK10-3	Taoling Township Zhou Family	D_2q	better	2.28	
ZK11-2	Xinwei Town Huolitang Drilling	D_3x^1	better	0.72	
1488	Longjingtang Village, Ping Township, Zhi City	$C_{2+3}ht$	better	2.22	
ZK13-4	Dongtian Village, Shiyang Town	D_3s	very poor	7.73	lead, cadmium, manganese, fluoride, oxygen consumption

4.2 Evaluation of water quality

On the whole, except for the hole ZK13-4, the water quality indicators of most of the representative groundwater source points in Xintian County meet the good water quality of the "Drinking Water Sanitation Standard" and the "Groundwater Quality Standard". The water quality is clear and transparent, without any odor, odor and foreign matter. The water is unpolluted and of good quality, suitable for the development and utilization of various purposes. The deterioration of groundwater quality only occurs in local areas, and the pollutants are mainly nitrite, cadmium, lead, manganese and fluoride. Therefore, due to the strong conversion of surface water and groundwater in this area, although the water supply sources and groundwater enrichment catchment areas of most small or scattered residents are far away from industrial and urban areas, they are close to residential areas and farmland, and are affected by domestic excrement, garbage, and chemical fertilizers and pesticides etc., the water source area is susceptible to surface environmental pollution. In order to keep the quality of the water source stable and not be affected by the pollution of the surface environment, it is necessary to establish an environmental sanitation protection zone during the development of the water source, improve the environmental management facilities and water quality testing system in the water source area, and effectively protect the environmental sanitation conditions of the water source to ensure the safety of water supply. Among the 16 groups of representative groundwater source water quality samples participating in the evaluation, there is 1 extremely poor grade and 1 poor grade, accounting for 12.5%, and the main excessive indicators are nitrite, lead, cadmium, manganese, fluoride, and oxygen consumption as shown above in Table 6.

5. Conclusions

According to the knowing of the natural hydrology and geological conditions of Xintian County, it can be seen that the whole area of Xintian County is dominated by carbonate rock distribution areas, which belong to the Xiangjiang River system. The strata in Xintian County are distributed from the Lower Paleozoic Cambrian to the Cenozoic Quaternary. It is located in a larger duplex syncline, and there is multiple first-order folds developed in the duplex syncline. The regional geology is an irregular elongated basin with strong karst dynamics, and there are tunnels or karst caves of different scales, which are conducive to the enrichment of groundwater.

The carbonate strata in the area have strong folds and developed fractures, resulting in multiple groups of joint fissures, especially the layered and longitudinal fissures, which have created good conditions for karst development channels. These channels are controlled by the strike of the strata, the direction of fissure development, and the tectonic line. When the lithology of the strata is the same, the karst development degree of the strata with gentle occurrence is higher, and the karst development degree of the stratum with steep occurrence is lower.

The karst groundwater resources in Xintian County are abundant but unevenly distributed. The shallow karst groundwater in the area is greatly affected by seasons and precipitation, the recharge sources are complex, and the relative dynamic changes of hydro-chemical components are large. The karst groundwater is neutral and alkaline water. The water is clear and transparent, colorless, odorless, and tastes good. All physical and sensory properties meet the requirements of the national drinking water hygiene standards. The content of toxic trace elements and fluoride in the water source is generally lower than the limit value specified by the national standard, and there is nearly no accumulation of toxic heavy metals. The overall water quality is of good quality, which is suitable for the development and utilization of various purposes.

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References

Ahmed S.M., Zhou B.X., Zhao H., Zheng Y.P., Wang Y. and Xia S.B. (2020), "Developing a composite vertical flow constructed wetlands for rainwater treatment", *Membr. Water Treat.*, **11**(2), 87-95. https://doi.org/10.12989/mwt.2020.11.2.087.

Ali A., Maryam K. and Giovanni M. (2022), "The middle Permian pyrophyllite-rich ferruginous bauxite, northwestern Iran, Irano–Himalayan karst belt: Constraints on elemental fractionation and provenance", *J. Geochem. Explor.*, **233**, 106905. https://doi.org/10.1016/j.gexplo.2021.106905.

An N., Yu L., Yan L.B. and Yang D. (2022), "Assessment of some trace elements accumulation in Karst lake sediment and Procambarus clarkii, in Guizhou province, China", *Ecotoxicol. Environ. Safety*, **237**, 113536. https://doi.org/10.1016/j.ecoenv.2022.113536.

Andrea D., Luigi C. and Domenico P., "Leaking pipes and the urban karst: A pipe scale numerical investigation on water leaks flow paths in the subsurface", *J. Hydrol.*, **603**, 126847. https://doi.org/10.1016/j.jhydrol.2021.126847.

Bae H.K. (2020), "The effect of Combined Sewer Overflows on river", *Membr. Water Treat.*, **11**(1), 49-57. https://doi.org/10.12989/mwt.2020.11.1.049.

Francesco P., Sara N.., Luca B, Alberto C., Alenka M., Jan R., Paolo S., Katja Š., Klemen L. andreja V. and Andrea N. (2021), "High spatial heterogeneity of water stress levels in Refošk grapevines cultivated in Classical Karst", *Agric. Water Manag.*, **260**, 107288. https://doi.org/10.1016/j.agwat.2021.107288.

Fraooq A.D., Ghulam J., Jerome P. and Shakeel A. (2021), "Groundwater recharge in semi-arid karst context using chloride and stable water isotopes", *Groundwater Sust. Develop.*, **14**, 100634. https://doi.org/10.1016/j.gsd.2021.100634.

Guillaume L., Nicolas P., Roland L., Alain D., Jonathan S., Matthieu F., David V., Julie G. and Jessica D.V. (2020), "Tracing water perturbation using NO^{3-}, doc, particles size determination, and bacteria: A method development for karst aquifer water quality hazard assessment", *Sci. Total Environ.*, **725**, 138512. https://doi.org/10.1016/j.scitotenv.2020.138512.

Jaqueline L.D., Francisco M.W.T., Hannes C., Tiago S.M., Virgínio H.M.L.N., Alcides N.S., Leonardo C.I. and Laís V.S. (2022), "Tufa associated with karst features in a fracture-system fed by meteoric water, Araripe basin, NE Brazil", *J. South Am. Earth Sci.*, **115**, 103772. https://doi.org/10.1016/j.jsames.2022.103772.

Li C. (2021), "Study on coordinated coupling development of agricultural economy and water resources environment", *Heilongjiang Hydraulic Sci. Technol.*, **49**(11), 217-220.

Liu H.Y., Chen B.L. and Wen D.S. (2007), "The characteristics and distribution pattern of karst water in western Hubei", *Resources Environ. Eng.*, **2**, 160-163. https://doi.org/10.16536/j.cnki.issn.1671-1211.2007.02.016.

Liu F. and Long X.T. (2022), "Investigation on geological structure and geothermal resources using seismic exploration", *Geothermics*, **106**, 102572. https://doi.org/10.1016/j.geothermics.2022.102572.

Long X.T., Liu F., Xie H.P., Lin W.J., Liu Y.G. and Li C.B. (2022), "Seismic geothermal resource exploration based on CPU/GPU collaborative parallel prestack time migration", *Acta Geologica Sinica*, 2022, **96**(5), 1742-1751.

Maryan K., Ali A.C., Ali A. and Gholamhossein S. (2020), "Geochemical and mineralogical features of karst bauxite deposits from the Alborz zone (Northern Iran): Implications for conditions of formation, behavior of trace and rare earth elements and parental affinity", *Ore Geol. Rev.*, **125**, 103691. https://doi.org/10.1016/j.oregeorev.2020.103691.

Ma X.L. (2021), "Research on hydrogeological conditions and formation mechanism of mineral water in Turgen, Xinjiang", *Ground Water*, **43**(4), 59-60+101.

Ma Z. (2016), "Experimental study on formation mechanism of mineral water in Jingyu County", Ph.D. Dissertation, Jilin University, Changchun, China.

Nataša R., Metka P., Matej B. and Astrid Š. (2021), "A multi-methodological approach to create improved indicators for the adequate karst water source protection", *Ecologic. Indicat.*, **126**, 107693. https://doi.org/10.1016/j.ecolind.2021.107693.

Peter B. and Grzegorz S. (2021), "Thermal anomaly and water origin in Weebubbie Cave, Nullarbor Karst Plain, Australia", *J. Hydrol. Regional Stud.*, **34**, 100793. https://doi.org/10.1016/j.ejrh.2021.100793.

Simon D.C., Julien R., Coffi B.C., Albert O., Claude D., Guillaume S., Konstantinos C., Nicolas P., Hendrik D. and Nicolas K.M.S. (2020), "Intra-specific variability in deep water extraction between trees growing on a Mediterranean karst", *J. Hydrol.*, **590**, 125428. https://doi.org/10.1016/j.jhydrol.2020.125428.

Simon A., Nathaniel D., Scravin T., Avik N., Allen K., Myknee S., Michael M., Nicholas H., Shaun K.R. and Alistair G. (2021), "Water quality challenges associated with industrial logging of a karst landscape: Guadalcanal", *Solomon Islands Marine Pollution Bulletin*, **169**, 112506. https://doi.org/10.1016/j.marpolbul.2021.112506.

Su C.T., Zhang F.W., Xia R.Y., Yao X., Zou S.Z., Luo F., Zhao G.S., Yang Y., Ba J.J. and Li X.P. (2017), "A study of the water-rock interaction of large rich Sr mineral spring in Xintian, Hunan Province", *Geol. China*, **44**(5), 1029-1030. https://doi.org/10.12029/gc20170515.

Wang Z.X., Li X.Q., Hou X.W., Zhang C.C., Gui C.L. and Zuo X.F. (2020), "Distribution characteristics and subsystem identification of Karst groundwater in Sangu spring basin", *Earth Environ.*, **48**(2), 228-239. https://doi.org/10.14050/j.cnki.1672-9250.2020.01.018.

Xia R.Y., Jiang Z.C., Zou S.Z., Cao J.H., Tan X.Q., Su C.T., Luo W.Q. and Zhou L.X. (2017), "Progress of hydrogeology and environmental geology comprehensive survey in Karst area", *Geol. Survey China*, **4**(1), 1-10. https://doi.org/10.19388/j.zgdzdc.2017.01.01.

Zhang H.B., Yang S., Gan X. and Luo F.H. (2018), "Study of the spatial distribution pattern and water quality characteristics of karst water resources in a typical anticlinal trough valley: A case study of Yiju river basin", *Carsologica Sinica,* **37**(1), 27-36. https://doi.org/10.11932/karst2017y56.

Zhang Y.L., Ding H.W., Fu D.L., Huang Z.B., Li A.J., Yan C.Y. and Jin X. (2020), "A study of enrichment environment and formation mechanism of strontium mineral water in Gansu Province", *Geol. China*, **47**(6), 1688-1701. https://doi.org/10.12029/gc20200607.

Zhao X.C. (2022), "Research on flood control problems of hydrology and water resources and environmental protection measures", *Agric. Sci. Tech. Inform.*, **1**, 49-51.

Zhao Y.W. (2021), "Hydrology environment protection and flood disaster reduction measures", *Environ. Sci. Manage.*, **46**(11), 157-161.

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