

Table S1. The well location, field parameters and major ion chemistry of the groundwater and lake water in the study area.

Sample	Type*	Latitude	Longitude	Depth	Temp.	pH	Eh	EC	TDS	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	CO ₃ ²⁻	NO ₃ ⁻	F ⁻
No.				(m)	°C		(mV)	(µs/cm)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
G1	1	39.27472	108.88306	19	10.4	8.01	-59.7	300	228.9	19.6	3.1	12.8	52.5	12.3	13.2	230.7	0.0	14.5	0.5
G2	1	39.28306	108.87833	55	13.6	8.26	-69.6	316	232.5	16.8	4.4	12.2	56.2	12.8	12.2	235.8	0.0	15.2	0.4
G3	1	39.29417	108.82750	10	9.8	8.38	-73.3	289	217.1	23.8	1.9	10.9	48.7	24.9	17.1	179.6	0.0	28.8	1.0
G4	1	39.28361	108.82833	50	10.1	8.24	-65.7	329	241.2	16.7	2.9	13.6	60.4	15.7	25.3	213.2	0.0	47.3	0.8
G5	1	39.28278	108.84139	150	9.2	8.21	-63.6	329	253.4	18.1	3.3	14.4	61.7	23.2	18.9	227.8	0.0	35.9	0.7
G6	1	39.28000	108.86000	180	11.7	8.11	-58.7	338	250.3	14.9	2.8	15.7	64.3	21.2	26.7	209.5	0.0	49.9	0.8
G7	1	39.28105	108.85611	85	13.0	8.23	-67.6	311	226.7	16.3	3.1	12.2	53.9	12.3	11.4	235.1	0.0	13.6	0.5
G8	1	39.28250	108.84556	135	12.1	8.01	-55.6	320	224.6	17.5	2.9	13.1	52.2	11.9	11.9	230.0	0.0	14.7	0.5
G9	1	39.28528	108.86778	120	12.2	8.29	-68.8	329	233.3	18.6	2.8	13.5	53.9	14.9	24.8	209.5	0.0	44.7	0.9
G10	1	39.28139	108.87806	150	11.4	8.36	-72.7	336	239.0	16.2	3.1	16.0	61.1	19.4	21.7	203.0	0.0	55.8	0.8
G11	1	39.26694	108.89750	80	10.1	8.44	-76.7	341	234.6	19.0	2.9	12.6	61.5	17.7	22.8	196.4	0.0	67.8	0.8
G12	1	39.26778	108.89861	50	9.1	8.08	-57.7	320	227.4	28.2	3.7	12.1	58.3	10.9	20.4	187.6	0.0	44.7	0.1
G13	2	39.26694	108.89667	200	11	8.56	-83.6	272	207.7	33.1	2.4	9.6	34.8	13.6	18.8	190.5	0.0	31.1	1.0
G14	2	39.26694	108.89667	200	8.3	8.38	-74.5	275	202.5	40.0	1.8	9.6	33.6	7.7	15.6	188.4	0.0	21.2	0.2
G15	2	39.25417	108.92139	150	12.7	8.41	-78.6	277	228.2	47.0	2.7	8.7	25.0	5.6	51.4	175.7	0.0	3.1	0.2
G16	3	39.25778	108.92694	120	8.2	8.62	-87.6	271	220.0	62.3	3.3	11.2	12.0	7.3	33.1	181.8	0.0	ND	0.2
G17	3	35.93111	109.39222	80	16.5	8.97	-109.9	295	238.6	74.6	1.2	8.2	7.2	4.4	46.7	192.8	0.0	ND	0.1
G18	3	39.23583	108.91139	150	13.2	8.64	-90.9	248	195.7	46.4	2.6	10.3	15.6	6.0	19.7	190.4	0.0	ND	0.7
G19	3	39.24500	108.92306	105	13.0	8.83	-100.7	282	243.9	73.9	1.5	8.4	10.8	4.7	42.1	205.0	0.0	ND	0.0
G20	3	39.25500	108.93194	160	7.4	8.65	-89.8	293	249.5	70.8	4.2	9.2	8.4	7.2	37.6	224.1	0.0	ND	0.4
G21	3	39.23333	108.91306	180	13.7	8.75	-96.7	256	171.8	47.4	1.7	12.5	7.4	5.6	21.5	151.3	0.0	5.0	0.3
G22	3	39.24389	108.94389	30	10.8	8.68	-92.1	273	234.8	67.8	1.6	9.2	9.3	3.5	44.5	197.7	0.0	ND	0.1

Table S1 continued

G23	3	39.18222	108.88361	150	15.1	8.33	−90.5	264	207.6	50.4	0.6	10.6	15.3	8.5	24.7	195.3	0.0	ND	1.0
G24	3	39.18000	108.89444	160	14.0	8.40	−93.8	272	211.2	56.7	1.3	10.9	12.7	9.5	29.8	180.6	0.0	ND	1.0
G25	3	39.18278	108.90250	100	13.1	7.69	−56.4	319	224.3	54.2	0.6	9.2	19.5	8.0	36.7	192.3	0.0	18.0	1.2
G26	3	39.18000	108.95417	30	12.9	8.72	−95.0	322	262.9	100.3	1.3	3.9	4.1	23.6	38.2	183.1	0.0	ND	1.1
G27	3	39.14833	108.99667	220	12.7	9.39	−130.8	300	228.9	88.7	1.0	2.7	4.6	10.5	30.0	183.1	0.5	ND	0.4
G28	4	39.17722	108.91889	100	14.0	8.76	−112.5	384	290.7	112.7	0.9	2.1	2.6	22.7	59.4	180.6	0.0	ND	1.3
G29	4	39.17833	108.92250	100	14.2	8.81	−115.4	455	343.4	128.6	1.2	2.6	4.0	39.0	76.4	183.1	0.0	ND	1.2
G30	4	39.17833	108.92278	30	15.2	8.84	−121	617	367.4	120.4	3.3	9.6	12.8	50.0	81.0	180.6	0.0	19.7	1.0
G31	4	39.16972	108.93694	170	13.7	9.16	−118.9	402	297.3	109.9	1.6	3.6	4.4	29.9	63.8	168.4	0.2	ND	0.3
G32	4	39.24806	108.93167	130	13.6	9.02	−111.6	295	234.9	74.7	1.1	6.5	6.9	5.7	58.3	163.5	0.0	ND	0.1
G33	4	39.16306	108.95333	120	11.9	8.95	−107.0	365	291.1	111.2	1.7	6.6	6.5	32.1	50.1	166.0	0.0	ND	0.3
G34	5	39.25638	108.92806	350	19.3	8.99	−137.5	922	677.85	223.84	2.64	0.38	15.45	53.95	324.18	107.39	2.40	ND	1.33
G35	5	39.25361	108.92944	450	18.7	8.77	−125.4	916	692.22	215.01	2.55	0.39	14.31	53.39	344.54	117.15	2.40	ND	1.06
G36	5	39.25500	108.93194	530	20.2	7.89	−79.4	942	697.05	213.75	3.07	0.28	15.29	54.28	355.66	102.51	2.40	ND	1.08
G37	5	39.25777	108.92694	560	21	8.78	−126.8	967	724.01	214.37	2.33	0.80	21.07	60.91	367.36	107.39	2.40	ND	1.06
G38	5	39.26777	108.89861	600	23	8.76	−116.9	1021	672.73	225.29	2.46	0.30	17.07	52.71	322.17	97.63	2.40	ND	1.52
L39		39.2108333	108.94861		18.4	9.99	−166	4050	5165.7	1879.5	228.0	49.1	21.3	1178.9	368.3	1493.7	693.7	ND	13.4
L40		39.1780556	108.92333		16.4	10.03	−166.9	4020	4464.5	1453.5	184.0	33.8	5.1	1140.1	341.4	1152.1	730.5	ND	13.4
L41		39.1783333	108.9225		18.3	9.97	−165.1	3820	4743.1	1738.8	144.7	41.7	142.4	1015.4	422.8	1149.6	662.5	ND	13.4
L42		39.1783333	108.92278		16.9	9.98	164.7	3670	4734.8	1768.0	157.1	42.9	4.9	1044.3	425.9	1335.1	624.1	ND	12.9
L43		39.1772222	108.91889		17.7	10	−166.1	3530	4487.8	1698.8	139.4	41.5	4.3	989.2	412.2	1137.4	633.7	ND	13.5

* Note: 1, 2, 3, 4 and 5 in the column of Type denotes Ca·Mg-HCO₃, mixed cations-HCO₃[−], Na-HCO₃, Na-HCO₃·SO₄ and Na-SO₄ type, respectively. “ND” in the column of NO₃[−] denotes not detected (below the detection limit of 0.01 mg/L).

Table S2. The minor ion chemistry, isotope chemistry, saturation indices and calculated ^{14}C age of the groundwater in the study area.

Sample No.	Type	Si (mg/L)	Sr ($\mu\text{g/L}$)	$^{87}\text{Sr}/^{86}\text{Sr}$	$\delta^{34}\text{S}_{\text{SO}_4}$ (‰)	$\delta^{18}\text{O}$ (‰)	$\delta^2\text{H}$ (‰)	$\delta^{13}\text{C}$ (‰)	^{14}C (pMC)	$^3\text{H}^*$ (TU)	SI Calcite	SI Dolomite	SI Gypsum
G1	1	2.71	377	0.711537		-8.3	-63.5	-10.0	89.2		0.51	0.53	-2.53
G2	1	6.02	448	0.711537		-8.2	-62.9				0.83	1.19	-2.55
G3	1					-7.9	-61.3				0.72	0.91	-2.43
G4	1					-7.4	-57.5				0.74	0.96	-2.20
G5	1					-8.5	-65.1				0.73	0.95	-2.32
G6	1					-8.6	-65.4				0.66	0.85	-2.16
G7	1	4.10	419	0.711444		-8.4	-63.6	-10.2	89.6		0.78	1.09	-2.59
G8	1	2.65	377	0.711191		-8.6	-65.2	-10.3	87.8		0.53	0.62	-2.58
G9	1					-8.3	-62.9				0.77	1.10	-2.25
G10	1					-8.8	-65.4				0.86	1.28	-2.27
G11	1					-8.5	-63.2				0.91	1.25	-2.24
G12	1					-8.2	-63.1				0.51	0.44	-2.29
G13	2					-8.9	-66.6				0.79	1.17	-2.53
G14	2					-8.9	-68.2				0.57	0.68	-2.61
G15	2					-10.0	-79.2				0.49	0.69	-2.24
G16	3	8.41	459	0.710754		-10.9	-82.5				0.33	0.72	-2.72
G17	3					-10.8	-82.6				0.54	1.39	-2.84
G18	3					-9.4	-71.6				0.56	1.13	-2.84
G19	3	2.78	493	0.710881		-11.0	-85.1				0.58	1.24	-2.70
G20	3	11.90	590	0.710703		-11.3	-86.5				0.27	0.65	-2.83
G21	3	1.66	503	0.711284		-9.9	-75.5				0.26	0.94	-3.11
G22	3					-11.1	-85.1				0.34	0.82	-2.72

G23	3					-9.8	-75.5				0.29	0.64	-2.75
G24	3					-10.8	-82.6				0.23	0.59	-2.75
G25	3					-10.5	-81.5	-11.0	34.1	ND	-0.27	-0.68	-2.47
G26	3	11.90	100	0.710024		-9.3	-77.3				0.03	0.21	-3.13
G27	3	5.78	602	0.710121		-10.5	-80.7				0.61	1.19	-3.24
G28	4					-10.6	-83.9				-0.15	-0.19	-3.17
G29	4					-10.7	-84.6				0.08	0.18	-2.89
G30	4	4.69	602	0.710794		-10.7	-83.0				0.60	1.30	-2.40
G31	4					-10.2	-82.6	-9.8	14.6	ND	0.38	0.89	-2.94
G32	4					-10.3	-80.8	-10.1	21.9	ND	0.46	1.10	-2.75
G33	4					-10.6	-82.8	-9.5	6.1	ND	0.19	0.46	-2.91
G34	5	11.6	951	0.709863	12.6	-11.0	-85.2	-7.0	1.70	ND	0.55	-0.24	-1.84
G35	5	11.5	954	0.709812	12.4	-10.8	-85.2	-8.0	1.40	ND	0.35	-0.60	-1.85
G36	5	11.4	925	0.709941	12.6	-10.8	-85.2				-0.50	-2.46	-1.80
G37	5				12.8	-10.9	-84.2				0.50	-0.12	-1.67
G38	5	10	748	0.709961	14.1	-10.9	-84.8	-8.3	2.40	ND	0.40	-0.64	-1.80

* Note: ND in the column of ^3H denotes not detected (below the detection limit).

Table S3. The mean chemical and isotopic compositions along with the standard deviations (s.d.) in the 5 types of groundwater in the study area.

Water type		type 1 (Ca·Mg-HCO3)			type 2 (mixed cations-HCO3)			type 3 (Na-HCO3)			type 4 (Na-HCO3·SO4)			type 5 (Na-SO4)		
Component	Unit	Mean	s.d.	No. of samples	Mean	s.d.	No. of samples	Mean	s.d.	No. of samples	Mean	s.d.	No. of samples	Mean	s.d.	No. of samples
TDS	mg/L	234.1	10.5	12	212.8	13.6	3	224.1	25.0	12	305.2	46.0	6	692.8	20.1	5
Temp.	°C	11.1	1.5	12	10.7	2.2	3	12.6	2.6	12	13.8	1.1	6	20.4	1.7	5
pH		8.22	0.14	12	8.45	0.1	3	8.67	0.41	12	8.92	0.15	6	8.6	0.4	5
Eh	mV	-65.8	6.8	12	-78.9	4.6	3	-94.9	17.7	12	-114.4	5.1	6	-117.2	22.4	5
Na ⁺	mg/L	18.8	3.7	12	40.1	7.0	3	66.1	7.0	12	109.4	18.5	6	218.4	5.6	5
K ⁺	mg/L	3.0	0.6	12	2.3	0.4	3	1.7	0.4	12	1.6	0.9	6	2.6	2.6	5
Mg ²⁺	mg/L	13.3	1.5	12	9.3	0.5	3	8.9	0.5	12	4.7	2.8	6	0.4	0.2	5
Ca ²⁺	mg/L	57.1	4.8	12	31.1	5.3	3	10.6	5.3	12	5.8	3.7	6	16.6	2.7	5
Cl ⁻	mg/L	16.4	4.8	12	9.0	4.2	3	8.2	4.2	12	29.5	15.0	6	55.0	3.3	5
SO ₄ ²⁻	mg/L	18.9	5.6	12	28.6	19.8	3	33.7	19.8	12	67.1	9.4	6	342.8	19.6	5
HCO ₃ ⁻	mg/L	213.2	19.0	12	184.9	8.0	3	189.8	8.0	12	174.1	8.3	6	106.4	7.2	5
NO ₃ ⁻	mg/L	36.1	18.5	12	18.5	14.2	3	2.4	5.4	12	3.3	8.1	6	ND	-	5
δ ² H	‰	-63.3	2.2	12	-71.3	6.8	3	-80.5	4.6	12	-83.0	1.3	6	-10.9	0.1	5
δ ¹⁸ O	‰	-8.3	0.4	12	-9.3	0.6	3	-10.4	0.7	12	-10.5	0.2	6	-84.9	0.4	5
⁸⁷ Sr/ ⁸⁶ Sr		0.711427	0.000163	12	-	-	3	0.710628	0.000477	12	0.710794	0.0	6	0.709934	0.000108	5
SI _{calcite}		0.71	0.14	12	0.62	0.16	3	0.31	0.25	12	0.26	0.28	6	0.26	0.43	5
SI _{dolomite}		0.93	0.28	12	0.85	0.28	3	0.74	0.56	12	0.62	0.57	6	-0.81	0.95	5
SI _{gypsum}		-2.37	0.16	12	-2.46	0.19	3	-2.84	0.22	12	-2.84	0.26	6	-1.79	0.07	5

Table S4. The mineralogical compositions of the aquifer core material in the study area.

Sample no.	depth m	Stratum group	quartz	K-feldspar	plagioclase	calcite	dolomite	ankerite	siderite	pyrite	hematite	analcite	Glauber's salt	clay
%														
R1	10	Huanhe	28.5	26.1	25.4	12.6	ND	ND	0.9	ND	ND	ND	ND	6.5
R2	112	Huanhe	30.3	26.5	19.0	19.7	ND	ND	ND	0.5	ND	ND	ND	4
R3	254	Huanhe	20.6	47.0	19	7.6	ND	ND	ND	ND	ND	ND	ND	4.9
R4	550	Luohe	56.1	8.9	10.7	3.2	0.4	1.0	0.9	ND	1.6	10.5	2.3	4.4
R5	602	Luohe	60.8	9.7	11.7	4.6	0.3	1.6	0.3	ND	ND	5.6	1.9	3.5

Note: ND denotes not detected (below the detection limit of 0.1%).

Table S5. A summary of the mass transfer for geochemical inverse modeling (The values are in mol/L): The phases and thermodynamic database are from PHREEQCI (version 2).

Phases	Path and Model Number											
	Precipitation to Type 1	Type 1 to Type 2			Type 2 to Type 3		Type 3 to Type 4				Type 4 to Type 5	
	Model 1	Model 2			Model 3		model 4				model 5	
Dolomite	4.63×10 ⁻⁰⁴	-	-	-	-	-	-	-	-	-	-	-
		2.80×10 ⁻⁰⁴	3.28×10 ⁻⁰⁴				2.09×10 ⁻⁰⁴	2.09×10 ⁻⁰⁴			1.35×10 ⁻⁰⁴	1.35×10 ⁻⁰⁴
Calcite	5.26×10 ⁻⁰⁴				1.43×10 ⁻⁰³		8.43×10 ⁻⁰⁵					
CO ₂ (g)	1.92×10 ⁻⁰³											
Gypsum	1.69×10 ⁻⁰⁴	2.27×10 ⁻⁰⁵	2.27×10 ⁻⁰⁵	2.27×10 ⁻⁰⁵	1.12×10 ⁻⁰⁴	1.12×10 ⁻⁰⁴	2.04×10 ⁻⁰⁴	2.04×10 ⁻⁰⁴	2.04×10 ⁻⁰⁴	2.04×10 ⁻⁰⁴	4.29×10 ⁻⁰⁴	4.29×10 ⁻⁰⁴
Halite	4.18×10 ⁻⁰⁴							4.26×10 ⁻⁰⁴	4.26×10 ⁻⁰⁴		8.76×10 ⁻⁰⁴	
CaX2		4.82×10 ⁻⁰⁴	4.82×10 ⁻⁰⁴	2.02×10 ⁻⁰⁴		4.63×10 ⁻⁰⁴	5.63×10 ⁻⁰⁵	1.41×10 ⁻⁰⁴	3.49×10 ⁻⁰⁴	3.49×10 ⁻⁰⁴		
MgX2				2.80×10 ⁻⁰⁴	9.11×10 ⁻⁰⁴					2.09×10 ⁻⁰⁴		
NaX		9.64×10 ⁻⁰⁴	9.64×10 ⁻⁰⁴	9.64×10 ⁻⁰⁴	1.82×10 ⁻⁰³	9.25×10 ⁻⁰⁴	1.13×10 ⁻⁰⁴	2.81×10 ⁻⁰⁴	6.99×10 ⁻⁰⁴	1.12×10 ⁻⁰³		
Glauber's salt											2.54×10 ⁻⁰³	2.54×10 ⁻⁰³

Table S6. The measured and assumed values for the calculation of $^{14}\text{C}_0$ for the groundwater in the study area.

Sample no.	Measured Values							Assumed Values				Calculated fraction factor			
	Temp.	pH	CO ₂ (aq)	CO ₃	HCO ₃	DIC	$\delta^{13}\text{C}_{\text{DIC}}$	$\delta^{13}\text{C}_g$	$^{14}\text{C}_g$	$\delta^{13}\text{C}_s$	$^{14}\text{C}_s$	$\epsilon_{a/g}$	$\epsilon_{b/g}$	$\epsilon_{a/s}$	$\epsilon_{b/s}$
	°C		(mmol/L)	(mmol/L)	(mmol/L)	(mmol/L)	(‰)	(‰)	(pMC)	(‰)	(pMC)	(‰)	(‰)	(‰)	(‰)
G1	10.4	8.01	0.12	0.02	4.47	4.69	-10.0	-21	100	0	0	-1.13	9.55	-10.85	-0.17
G7	13.0	8.23	0.07	0.03	4.49	4.69	-10.2	-21	100	0	0	-1.11	9.25	-10.67	-0.31
G8	12.1	8.01	0.11	0.02	4.45	4.66	-10.3	-21	100	0	0	-1.12	9.35	-10.74	-0.26
G25	13.1	7.69	0.03	0.03	3.47	3.59	-11.0	-21	100	0	0	-1.11	9.24	-10.67	-0.32
G31	13.7	9.16	0.00	0.24	2.56	2.83	-9.8	-21	100	0	0	-1.11	9.17	-10.63	-0.35
G32	13.6	9.02	0.00	0.18	2.49	2.70	-10.1	-21	100	0	0	-1.11	9.18	-10.63	-0.34
G33	11.9	8.95	0.01	0.10	3.41	3.55	-9.5	-21	100	0	0	-1.12	9.38	-10.75	-0.25
G34	19.3	8.99	0.00	0.14	3.18	3.41	-7.0	-21	100	0	0	-1.09	8.54	-10.25	-0.63
G35	18.7	8.77	0.00	0.19	2.90	3.14	-8.0	-21	100	0	0	-1.09	8.60	-10.29	-0.60
G38	23.0	8.76	0.00	0.31	2.91	3.28	-8.3	-21	100	0	0	-1.07	8.13	-10.01	-0.81

Table S7. The calculated $^{14}\text{C}_0$ values and the corrected ^{14}C ages using various models for the groundwater in the study area.

Sample no.	Measured $^{14}\text{C}_{\text{DIC}}$	Calculated $^{14}\text{C}_0$ (pMC)			Apparent Age	Corrected ^{14}C Age (years BP)				Average Calendar Age
	pMC	Eichinger	Han & Plummer	IAEA	(years BP)	Eichinger	Han & Plummer	IAEA	Average	(years BP)
G1	89.2	-	-	modern	945	-	-	modern	modern	modern
G7	89.6	-	-	modern	908	-	-	modern	modern	modern
G8	87.8	-	-	modern	1076	-	-	modern	modern	modern
G25	34.1	41.47	41.77	95.26	8894	1617	1677	8493	3929	4340
G31	14.6	37.17	37.19	84.36	15906	7726	7730	14501	9986	11198
G32	21.9	38.35	38.35	87.01	12554	4632	4632	11405	6890	7813
G33	6.1	36.07	36.05	83.29	23121	14691	14687	21610	16996	19965
G34	1.7	25.62	25.72	57.14	33683	22424	22456	29057	24646	28125
G35	1.4	29.67	29.71	65.62	35288	25244	25256	31807	27436	30902
G38	2.4	30.58	30.65	65.54	30832	21036	21057	27341	23145	26736