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ORIGINAL ARTICLE

Damming effects on dissolved inorganic carbon in different kinds of reservoirs in Jialing River, Southwest China

Gaoyang Cui[1,2] · Xiaodong Li[3] · Qinkai Li[1,2] · Jun Huang[1,2] · Yuele Tao[3] · Siqi Li[3] · Jun Zhang[3]

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Abstract To assess the effects of river damming on dissolved inorganic carbon in the Jialing River, a total of 40 water samples, including inflow, outflow, and stratified water in four cascade reservoirs (Tingzikou, Xinzheng, Dongxiguan, Caojie) were collected in January and July, 2016. The major cations, anions, and $\delta^{13}C_{DIC}$ values were analyzed. It was found that the dissolved compositions are dominated by carbonate weathering, while sulfuric acids may play a relatively important role during carbonate weathering and increasing DIC concentration. Different reservoirs had variable characteristics of water physiochemical stratification. The DIC concentrations of reservoir water were lower in summer than those in winter due to the dilute effects and intensive aquatic photosynthesis, as well as imported tributaries. The $\delta^{13}C_{DIC}$ values in Tingzikou Reservoir were higher during summer than those in winter, which indicated that intensive photosynthesis increased the $\delta^{13}C_{DIC}$ values in residual water, but a similar trend was not obvious in other reservoirs. Except for in Xinzheng Reservoir, the $\delta^{13}C_{DIC}$ values in inflow and outflow reservoir water were lower than those in the surface water of stratified sampling in summer. For stratified sampling, it could be found that, in summer, the Tingzikou Reservoir $\delta^{13}C_{DIC}$ values significantly decreased with water depth due to the anaerobic breakdown of organic matter. The significant correlation ($p < 0.01$ or 0.05) between the DIC concentrations, the $\delta^{13}C_{DIC}$ values and anthropogenic species ($Na^{+}+K^{+}$, Cl^{-}, $SO_4^{2-}$and NO_3^{-}) showed that the isotope composition of DIC can be a useful tracer of contaminants. In total, Tingzikou Reservoir showed lacustrine features, Xinzheng Reservoir and Dongxiguan Reservoir had "transitional" features, and Caojie Reservoir had a total of "fluvial" features. Generally, cascade reservoirs in the Jialing River exhibited natural river features rather than typical lake features due to characteristics of reservoir water in physiochemical stratification, spatiotemporal variations of DIC concentrations and isotopic compositions. It is evident that the dissolved inorganic carbon dynamics of natural rivers had been partly remolded by dam building.

Keywords River damming · Water chemistry · Reservoir types · Dissolved inorganic carbon isotope composition · DIC concentration

1 Introduction

A river acts as a bridge that connects the material circulation of the continents and oceans. This transportation of biogenic elements (C, N, P, Si, etc.) has an important impact on marine and riverine aquatic ecosystems (Meybeck 1982; Ittekkot 1988; Liu et al. 2009). However, interception and storage of hydropower dams had greatly changed the characteristics and quantities of the river-to-ocean material transportation system in past few decades due to needs of economic development, resulting in a lot of dams building (Humborg et al. 1997; Milliman 1997; Klaver et al. 2007). Originally, hydrodynamic conditions

✉ Xiaodong Li
xiaodong.li@tju.edu.cn

1 State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550081, People's Republic of China

2 University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China

3 Institute of Surface-Earth System Science, Tianjin University, Tianjin 300072, People's Republic of China

had been changed because of the dam effect; with appearance of "limnology effects" such as thermal stratification, carbon cycle process will be altered due to the alterations of aquatic organism distribution and metabolic direction/strength (Wang et al. 2012; Bonnet et al. 2000; Becker et al. 2008; Liu et al. 2014). Until now, there were many studies focused on the "limnology effect" of reservoirs, including environment, aquatic ecology, hydraulics, hydrodynamics and geochemistry, which included studies on hydrology and reservoir management (Tufford and Mckellar 1999; Casamithjana et al. 2003; Ducan 1990; Bayley 1991), physiochemical or biological stratifications in reservoirs (Ma et al. 2013; Wang et al. 2005); activation and release of C, N, P, Si, Hg etc. in water–sediment interfaces (Louchouarn et al. 1993; Jossette et al. 1999; Wang et al. 2000); interception effect of nutrients in dammed rivers (Humborg et al. 1997, 2000; Jossette et al. 1999; Ran et al. 2009); source-sink effects of C in reservoir areas (Giles 2006; Barros et al. 2011; Knoll et al. 2013) and variation of aquatic ecosystems (Xie 2003; Wang et al. 2008).

As an important biogenic element, carbon has close relationships with the circulation of other nutrients, energy flow, CO_2 dynamics and trophic states in the "River-Reservoir-River" system (Li et al. 2015). The DIC concentrations and isotope compositions can reflect the geochemical behaviors and biogeochemical characteristics of carbon (Liu 2007). Present studies mainly focus on source, migration or transformation of carbon in natural lakes (Quay et al. 1986; Herczeg 1987; Wachniew and Różński 1996), meanwhile there were a few studies on reservoir DIC cycling, for example, Jędrysek et al. (2006) studied diurnal variations of $\delta^{13}C_{DIC}$ compositions in the Sulejów reservoir. Wang et al. (2011) studied the DIC and $\delta^{13}C_{DIC}$ changes in two reservoirs in the Wujiang River and Yu et al. (2008) studied the DIC concentrations and isotope compositions in cascade reservoirs in the Wujiang drainage basin. The studies of carbon cycling in reservoir showed that the DIC concentrations of reservoir water decreased from the tail to the front area of dam, while the $\delta^{13}C_{DIC}$ values were more positive in summer and autumn than in winter and spring, and that the DIC concentrations increased but $\delta^{13}C_{DIC}$ values decreased in profiled water. Liu et al. (2014) studied on the features of DIC in the Wulixia reservoir in Guangxi and found similar results with those from the Wujiang River. However, Wu et al. (2012) found there were no significant differences in DIC concentrations and $\delta^{13}C_{DIC}$ values in water column. Besides, Zhang et al. (2014) described spatiotemporal distribution of DIC and DOC in main stem of the Yangtze River and effects of the Three Gorges Reservoir; Yu et al. (2009) discussed spatiotemporal characteristics of DIC and its isotopic compositions in the Hongjiadu Reservoir in the Wujiang River drainage basin, etc.

However, most of this relevant research is focused on a single reservoir or several independent reservoirs in different river drainage basins. Some researches studied on the DIC concentrations and $\delta^{13}C_{DIC}$ values in cascade reservoirs in the same drainage basin. The Jialing River is an important tributary of the Yangtze River and there were many reservoirs constructed along the Jialing River but very few studies related to the DIC concentrations and isotope compositions in this drainage basin (Li et al. 2015). Thus, four typical reservoirs in middle-lower reach of the Jialing River were selected, while spatiotemporal characteristics of the DIC concentrations and $\delta^{13}C_{DIC}$ values were analyzed. Then, source, migration, transformation and controlling factors of DIC in different reservoir types will be discussed.

2 Study area

2.1 Topography and geology

The Jialing River, a major tributary to the upper reaches of the Yangtze River, originated from the Qinling Mountains in the Shanxi Province, and carves southward through hilly lands in the middle Sichuan Basin, cutting across the Paralleled Ridge-Valley of East Sichuan. The main stream is 1120 km long, with a drainage area of 1.6×10^4 km^2 and mean annual runoff discharge of 704×10^8 m^3. The middle and lower reaches of the Jialing River are distributed in the Mesozoic and Cenozoic Sichuan Syneclise. The Jialing River itself has four major tributaries, the Xihanshui River, the Bailongjiang River, the Qujiang River and the Fujiang River, which import into the main channel at Lveyang, Zhaohua and Hechuan (Qujiang and Fujiang River), respectively (Fig. 1).

In middle and lower courses of the Jialing River, the Sichuan Basin comprises a relatively un-deformed part of the Yangtze platform. And there is a lower terrain with an elevation of 250–600 m. From Guangyuan to the south, the formation lithology is composed of Cretaceous continental clastic sedimentary rocks, Jurassic purplish red sand-mudstone, Quaternary loose sediment accumulation of glacier and ice-water and also scattered outcrops of Triassic carbonate rocks of the lower reaches (Fig. 1).

2.2 Climate and soil

The Jialing River basin has a subtropical monsoon humid climate. Mean annual precipitation is 1010–1250 mm in middle and lower Jialing River zones, mostly from May to

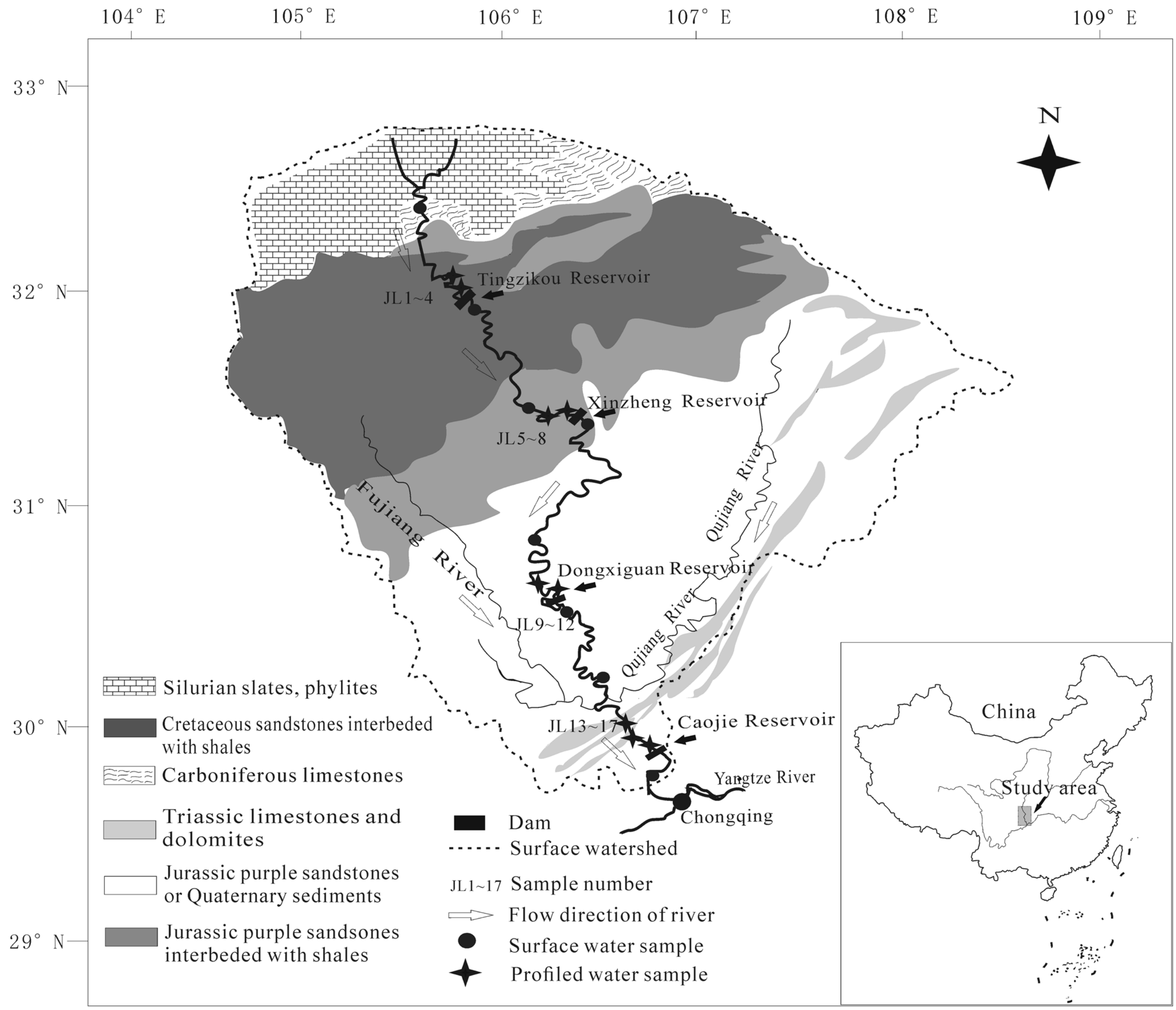

Fig. 1 Map showing sampling sites and lithology along middle and lower reaches of the Jialing River

October, accounting for about 85% of the total annual precipitation (Changjiang Water Resource Commission, 2003). The Jialing River had an average annual runoff of 696×10^8 m^3 in the same period of 1956–1979, and consequently, water discharge is also highly seasonal (Water conservancy and electric power department of Sichuan Province, 1991). The most widely distributed soils are calcareous purple soils, neutral purple soils, yellow soil and alluvial soils. There are other soil types such as red soil, brown soil (Bureau of Geology and Mineral Resources of Sichuan Province, 1991).

The Jialing River basin is located in center of the Sichuan Basin, and acid rain pollution is aggravating because of rapid economic growth and sulfur-content coal combustion in recent decades. A series of reservoirs have been built and put into use since 1970s, and original hydrological situation and characteristics of water environment have been greatly changed. To a certain extent, natural chemical weathering processes have also been affected by the development of agriculture and industry, indirectly.

3 Sample collection and analyses

3.1 Field sampling and data collection

Four reservoirs were selected from the Jialing catchment (Tingzikou Reservoir, Xinzheng Reservoir, Dongxiguan Reservoir and Caojie Reservoir from midstream to

Table 1 Major characteristics of reservoir in this study

Item	Tingzikou Reservoir	Xinzheng Reservoir	Dongxiguan Reservoir	Caojie Reservoir
Reservoir type	Mountain-valley type	Transition between valley-plain	Transition between valley-plain	River channel type
Reservoir age (till 2016)	2	10	20	5
Levels of normal water/flood control/dead storage (m)	458/447/438	324/322/–	248.5/241/–	203/200/178
Regulation way	Annual	Daily	Daily	Daily/weekly
Surface area (km^2)	80.9	25.6	17.8	72.4
Distance from river mouth (km)	574	429	223.6	62.1
Capacity of reservoir ($10^8 \cdot m^3$)	40.67	3.402	1.65	22.12
Drainage area (km^2)	61,089	69,403	78,247	156,000
Average surface width (m)	600	–	–	400
Annual mean runoff ($10^8 \cdot m^3$)	188.8	246.6	277.2	669.5
Average flow ($m^3 \cdot s$)	598	781	891	2120
Backwater distance (km)	150	40	50	75
Dam height/crest elevation (m)	116/465	41/339	47.2/253	83/221.5

"–"indicates no available data

downstream, respectively), See Table 1 for more details. A total of 80 samples were collected in Jan (low flow season, dry season) and Jul (high flow season, rainy season) from midstream to downstream, include samples of inflow (surface water), outflow (surface water) and reservoir area (profiled water). Sampling depths were chosen based on the structure of thermal profiles and water depths in all reservoirs (ex: 0, 5, 10, 15, 30 and 60 m for water depths around 60 m). The sampling sites for surface and stratified water are shown in Fig. 1. JL1, JL5, JL9 and JL13 were inflow samples, and JL4, JL8, JL12 and JL17 were outlets of reservoirs, and JL3, JL4, JL6, JL7, JL10, JL11, JL14, JL15 and JL16 sampled from water column inside reservoirs.

Water temperature, dissolved oxygen and pH were measured in situ using an YSI 6920, which had been calibrated. Alkalinity (counted as HCO_3^-) was determined by Gran titration using 0.02 mol HCl within 8 h. All HDPE bottles used for collecting water samples were acid-washed and cleaned with distilled water in laboratory previously. All samples were filtered in field using 0.45 μm Millipore nitrocellulose filter and 15 mL of these samples were stored for measuring anions, while another 15 mL were acidified with ultra-pure HNO_3 to pH < 2 for cationic determination. Both anionic and cationic samples were stored at 4 °C in refrigerator. The other water samples (60 mL) were filtered by pressure filtration through 0.45 μm cellulose acetate filter and stored in previously acid-washed HDPE bottles with air-tight caps, and then conserved in refrigerator at 4 °C for $\delta^{13}C_{DIC}$ measuring. Vials for $\delta^{13}C_{DIC}$ measuring were injected with $HgCl_2$ solution to poison the samples.

3.2 Analysis

Major cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) and Si concentrations were determined with ICP-OES, and anions (SO_4^{2-}, NO_3^- and Cl^-) were analyzed using a Dionex ICS90 (with a SE < 5%). Generally speaking, a CBE within ±5% is acceptable (Li et al. 2011). In this study, the extent of Tz^+–Tz^- charge characterized by the normalized inorganic charge balance (NICB = (Tz^+–Tz^-)/Tz^+) ranged from 2.6% to 4.99%, which was considered acceptable.

Then, CO_2 was collected using the off-line vacuum system (Atekwana and Krishnamurthy 1998), 40 mL water samples was injected by syringe into glass bottles that were pre-filled with 1 mL 85% phosphoric acid. The CO_2 was extracted and purified after cryogenic removal of H_2O using a liquid nitrogen-ethanol trap; finally, CO_2 was transferred cryogenically into a tube for isotope measurement (Li et al. 2008a, 2008b). Carbon isotope ratios of the DIC that determined on a Finnigan MAT252 mass spectrometer are reported in δ notation relative to PDB (‰), and have a precision of 0.1‰. All analyses were conducted at the Institute of Geochemistry, Chinese Academy of Science.

$$\delta^{13}C_{DIC}(‰) = \left(\left(R_{sample}/R_{PDB}\right) - 1\right) \times 1000$$

4 Results and discussion

4.1 Chemical composition of surface water

Variations of major ion compositions in surface water samples are shown in the anion and cation ternary diagrams (Fig. 2a and b). Total cationic charge (Tz^{+}= Na^{+}+–K^{+}+2Ca^{2+}+2 Mg^{2+}) ranged from 3.67 (Jul) to 4.02 (Jan) with an average of 3.85 meq/L, three times more than the world rivers' average of 1.25 meq/L (Meybeck 1981), and higher than the average of the Yangtze River (2.80 meq/L; Han and Liu 2004). The total anionic charge (Tz^{-} = HCO_3^- + Cl^- + NO_3^- + 2 SO_4^{2-}) ranged between 3.49(Jul) and 3.91(Jan) with an average of 3.70 meq/L. Calcium is the dominant cation with proportions from 61.1% to 63.2%, magnesium from 25.6% to 27.1%, and Na^{+}+K^{+} from 11.3% to 11.7% of the total cations, respectively. Silicon in study area is negligible. Bicarbonate is the dominant anion with proportions from 69% to 71% of total anions. The second major anion is SO_4^{2-}, next NO_3^- + Cl^-, proportioning from 21% to 24% and from 7% to 8% of total anions, respectively.

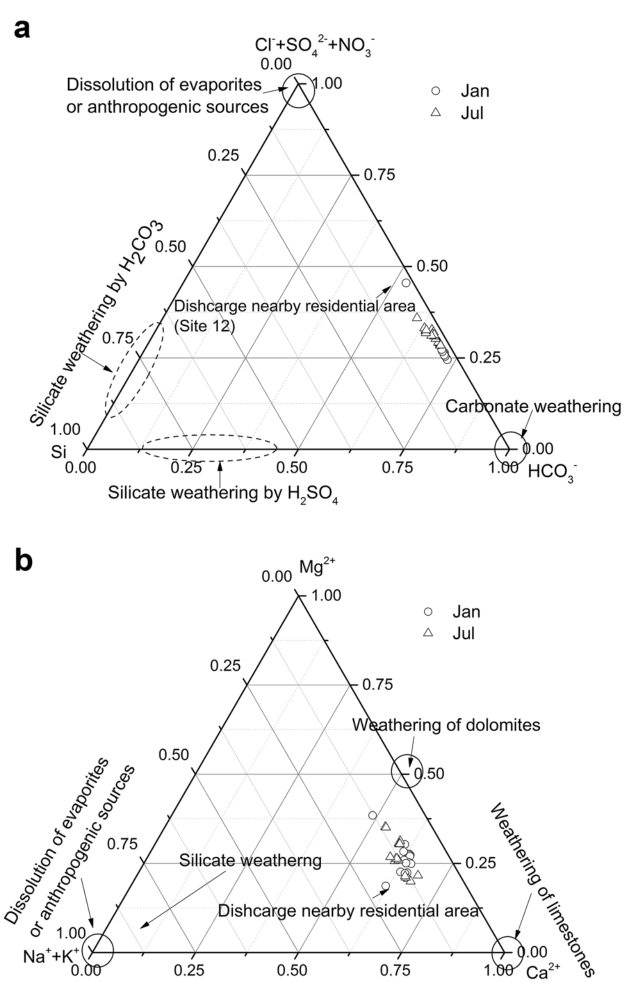

Fig. 2 Ternary diagrams showing anion, Si (diagram **a**) and cation compositions of surface water (diagram **b**)

On a short time scale, carbonate minerals are actively involved in global carbon cycle due to high solubility (Yuan 1997). It has been proven that carbonate minerals are the main controlling factor of riverine DIC pool, even with a small quantity (Barth et al. 2003). According to mass balance considerations, the water body can be mainly characterized as HCO_3^- – Ca^{2+}·Mg^{2+} type. Combined with lithologic distribution (Fig. 1) and water chemistry ternary diagram (Fig. 2), the solute compositions are dominated by carbonate weathering (include limestone and dolomite). The sodium excess over chloride (Na:Cl = 1.81–1.97) requires input from aluminosilicate weathering, but is negligible (Hu et al. 1982). The low silica value may be an artefact of removal by diatoms in the reservoirs upstream from sampling site (Hu et al. 1982). Besides, co-variation of the equivalent ratios of [Ca^{2+}+Mg^{2+}] and [SO_4^{2-} + HCO_3^-] indicate that significant additional SO_4^{2-} is required to achieve ionic balance (Fig. 3a and b), which implied that sulfuric might play a relatively important role in carbonate weathering in studied area.

Hu et al. (1982) investigated major ion chemistry in the main stream of Changjiang River and found Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^- and SO_4^{2-} concentrations of 2.17, 0.68, 0.3, 0.04, 0.18 and 0.62 (meq/L), respectively. Chen et al. (2002) reported major ion compositions of Jialing River as follows: 2.06, 0.78, 2.35, 0.55, 0.13 and 0.097 (meq/L) for Ca^{2+}, Mg^{2+}, HCO_3^- SO_4^{2-}, Cl^- and SiO_2, respectively. Chetelat et al. (2008) reported main ion compositions of the Jialing River mouth in Chongqing as follows: 2.096, 0.78, 0.22, 0.06 and 0.89 (meq/L) for Ca^{2+}, Mg^{2+}, Cl^-, NO_3^- and SO_4^{2-}, respectively. However, major ion equivalent concentrations of this study are higher than that of previous studies (Table 2), indicating the accumulation effect due to the increasing intensity of rocky weathering and anthropogenic inputs over time. Interestingly, the outflow of the Dongxiguan Reservoir had relatively high contents of Cl^{+}+ NO_3^- + SO_4^{2-} and Na^{+} + K^{+} (site 12; Fig. 2a and b), which might have resulted from domestic sewages.

4.2 Characteristics of seasonal physiochemical stratification

Thermal stratification of water is one of the most important characteristics of lakes and reservoirs that differs from rivers, and is the most significant control factor of many chemical-biological processes in deep water reservoirs (Liu et al. 2009). In this study area, most of reservoirs belonged to polymictic or oligomictic types (Liu et al. 2014). For example, there was an obvious thermal stratification in

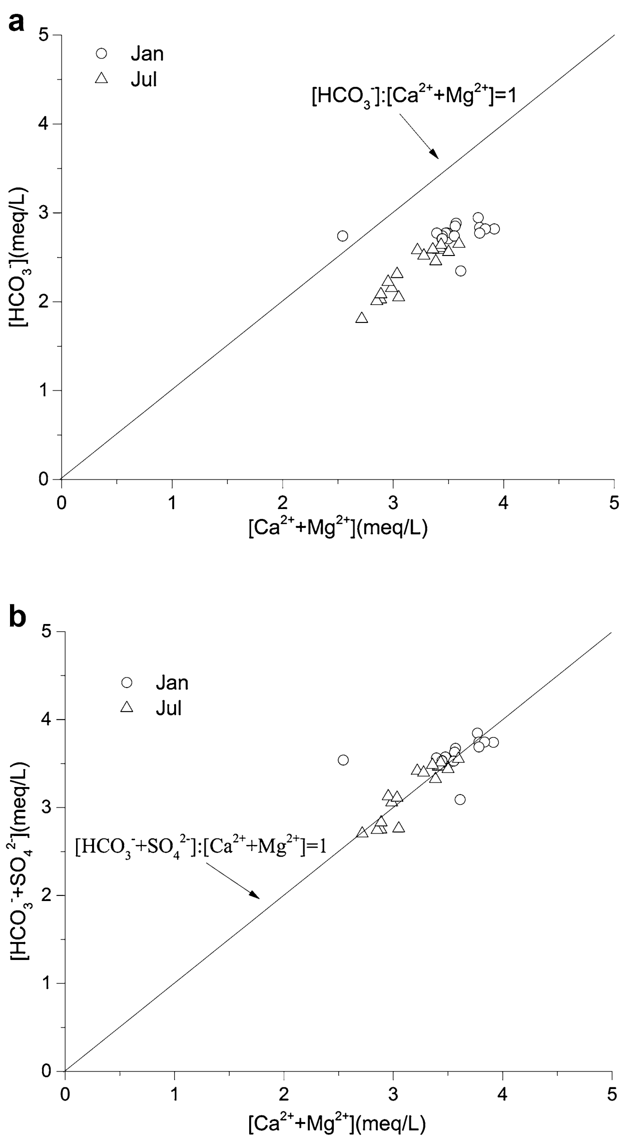

Fig. 3 Co-variation of (**a**) $[HCO_3^-]$ vs. $[Ca^{2+}+Mg^{2+}]$; (**b**) $[HCO_3^-+SO_4^{2-}]$ vs. $[Ca^{2+}+Mg^{2+}]$ in surface water samples of the Jialing River

Tingzikou Reservoir during summer, with an average water temperature of 27.56 and 8.81 °C in top and hypolimnetic water, respectively, and the temperature difference was up to 18.75 °C (Fig. 4). However, weak thermal stratification was observed in Xinzheng Reservoir and Dongxiguan Reservoir, with average temperatures of 26.44 and 29.11 °C in top water and of 25.82 and 28.1 °C in bottom water, respectively (Fig. 4). Additional, there was no obvious thermal stratification of profiled water in Caojie Reservoir, while thermal stratification disappeared in all reservoirs in the winter (Fig. 4).

The variation characteristics of DO contents in profiled water were similar to those of T (°C), and vertical exchanges of waters were effectively limited by thermal stratification in summer. Then, aerobic and anaerobic environments were generated in the epilimnion and hypolimnion, respectively. Variable characteristics of DO contents in the water column were observed in different reservoirs (Fig. 4). During summer, the DO contents in Tingzikou Reservoir decreased continuously with water depth, and ranged from 9.26 mg/L (top water) to 6.21 mg/L (bottom water). The DO contents in the top water near the water–air interface were close to saturation of local climatic condition due to direct connection with air and wind mixing, while the restoration of oxygen tended to become more difficult along with increase of water depth, and disappearance of photosynthesis in the hypolimnion combined with degradation of organic matter in sediments lead to oxygen depletion. Therefore, the DO contents of profiled water usually decreased linearly with water depth in summer (Ma et al. 2013). In Xinzheng Reservoir and Dongxiguan Reservoir, the average DO contents in water column slightly decreased with water depth increases, which ranged from 7.78 mg/L (top water) to 6.98 mg/L (bottom water) and from 6.52 mg/L (top water) to 5.42 mg/L (bottom water), respectively (Fig. 4). There was also a small difference (0.17 mg/L) between surface water and hypolimnetic water in Caojie Reservoir (Fig. 4). In winter, profile variations of DO contents were not obvious (Fig. 4), while the average DO contents were higher in winter than that in summer due to disappearance of thermal stratification, frequently vertical exchange of water column and consumption mechanism of hypolimnetic oxygen was compensated by oxygen renewal (Ma et al. 2013). Besides, lower water temperature (°C) would result in reduction of photosynthesis and consumption of DO.

In thermal stratification period, change trends of pH values in water column were similar to that of DO contents and temperature (°C), thus pH values decrease with water depth on the whole, especially in Tingzikou Reservoir (Fig. 4). In rainy season, average pH values of Tingzikou reservoir were 8.42 (top water) and 7.1 (bottom water), respectively (Fig. 4), and this obvious acidification trend was resulted from the anaerobic decomposition of organic matter in water column and sediments. Moreover, surface waters in reservoir area were affected by the inflow of upstream significantly, while river section was dominated by carbonate weathering and usually had high pH values. The average pH values in water column of Xinzheng Reservoir and Dongxiguan Reservoir ranged from 7.87 (top water) to 7.5 (bottom water) and from 7.77 (top water) to 7.54 (bottom water), respectively (Fig. 4), but the differences were not significant. There were no obvious profile variations of pH values in Caojie Reservoir in summer, while there were also no evident profile changes of pH values in all of the reservoirs in winter (Fig. 4).

Generally, stability of thermal stratification in summer was affected by water turbulent kinetic energies, vertical

Table 2 The contents and isotopic composition of carbon in study area (unit in mg/L, except $\delta^{13}C_{DIC}$ in ‰)

Date	Sample	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	SiO_2	$\delta^{13}C_{DIC}$
Jul 2016	JL1	110.21	4.27	43.12	3.75	5.71	2.32	41.24	7.84	7.56	−12.32
	JL2 (0 m)	131.40	4.52	43.37	2.96	7.68	1.87	36.01	14.23	4.22	−3.81
	JL2 (30 m)	160.37	4.27	44.11	4.56	7.84	1.73	47.73	14.46	5.14	−7.48
	JL2 (60 m)	178.03	4.52	43.62	3.65	7.56	1.84	50.85	15.11	5.35	−7.13
	JL3 (0 m)	135.64	4.46	43.35	3.09	7.53	1.76	35.73	14.01	4.22	−4.49
	JL3 (5 m)	135.64	4.55	42.84	3.05	7.60	1.82	35.44	13.91	4.24	−4.95
	JL3 (15 m)	161.08	4.23	43.31	3.91	7.83	1.91	46.00	14.33	5.29	−8.04
	JL3 (30 m)	167.44	4.09	43.30	4.51	7.38	1.77	47.80	14.26	5.41	−7.12
	JL3 (60 m)	178.03	3.97	36.84	6.12	7.56	1.83	53.63	15.04	5.33	−9.67
	JL4	161.78	4.24	43.27	4.11	7.76	1.87	46.99	14.95	5.43	−7.24
	JL5	157.54	5.33	42.30	3.73	7.84	2.09	44.94	13.99	5.00	−7.76
	JL6 (0 m)	158.96	5.23	41.37	3.69	7.75	2.05	45.19	13.99	4.96	−10.15
	JL6 (5 m)	154.72	5.22	41.80	3.78	7.91	2.12	47.46	14.47	6.17	−8.67
	JL6 (15 m)	152.60	5.38	41.53	3.96	7.98	2.15	45.25	14.60	5.27	−8.90
	JL7 (0 m)	156.13	5.43	42.17	3.76	8.04	2.13	46.29	14.24	5.35	−9.77
	JL7(5 m)	156.13	5.21	42.30	3.93	7.89	2.04	46.74	14.03	5.48	−8.52
	JL7 (10 m)	163.20	5.07	41.74	3.76	7.83	2.08	45.11	13.75	5.01	−8.36
	JL7 (15 m)	164.61	5.26	41.98	3.76	7.92	2.09	45.32	14.19	5.17	−6.33
	JL8	161.08	5.23	41.85	3.89	7.77	2.03	45.39	13.98	5.13	−9.01
	JL9	157.37	8.98	40.20	4.24	10.02	3.16	45.20	11.51	5.79	−10.86
	JL10 (0 m)	157.90	8.05	42.97	4.91	9.91	3.16	46.79	12.22	5.82	−10.19
	JL10 (5 m)	158.96	8.15	43.80	4.74	9.89	3.17	46.77	12.18	5.51	−10.20
	JL10 (15 m)	157.90	8.14	43.07	4.59	9.81	3.23	46.46	12.43	5.65	−10.85
	JL11 (0 m)	149.77	7.95	41.69	4.64	9.53	2.91	47.87	11.91	5.87	−10.86
	JL11 (5 m)	152.60	7.87	41.89	4.82	9.60	3.04	46.29	12.14	5.55	−10.76
	JL11 (10 m)	154.72	8.03	42.20	4.60	9.94	2.98	46.46	12.17	5.75	−10.87
	JL11 (20 m)	154.72	7.98	42.36	4.63	9.53	3.01	47.02	12.00	5.64	−10.94
	JL12	153.66	8.09	42.13	4.88	9.47	2.95	45.71	11.90	5.31	−11.46
	JL13	140.94	8.40	38.40	3.32	9.72	3.29	41.71	11.40	6.58	−13.51
	JL14 (0 m)	123.63	7.96	34.72	5.06	8.14	3.11	44.03	8.22	7.35	−13.38
	JL14 (40 m)	122.93	8.00	35.14	4.95	8.34	3.19	43.22	8.33	7.21	−12.89
	JL15 (0 m)	125.05	8.05	34.11	4.82	8.39	3.23	47.04	8.37	7.99	−12.88
	JL15 (20 m)	123.63	7.82	34.65	4.82	8.16	3.10	42.89	8.23	7.30	−12.87
	JL15 (40 m)	123.63	7.97	34.61	5.24	8.27	3.25	43.38	8.37	7.26	−13.18
	JL16 (0 m)	122.40	8.18	35.38	5.20	8.29	3.20	43.18	8.33	7.17	−12.59
	JL16 (5 m)	124.34	8.01	35.42	5.42	8.10	3.13	43.25	8.17	7.22	−12.58
	JL16 (10 m)	122.93	8.14	35.04	4.85	8.19	3.19	44.16	8.24	7.47	−12.55
	JL16 (15 m)	122.22	8.09	35.17	5.23	8.47	3.21	42.51	8.45	7.05	−12.84
	JL16 (30 m)	122.93	8.15	35.10	5.33	8.23	3.19	43.18	8.42	7.22	−13.47
	JL17	127.17	8.37	35.78	4.98	8.36	3.29	43.48	8.58	7.06	−12.74
	Average	146.10	6.52	40.2	4.38	8.34	2.59	44.84	11.92	5.94	−10.05

Table 2 continued

Date	Sample	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	SiO_2	$\delta^{13}C_{DIC}$
Jan 2016	JL1	179.66	4.59	43.20	3.94	7.59	1.73	50.28	15.07	5.74	−5.66
	JL2 (0 m)	175.82	4.21	37.95	4.28	7.16	1.99	49.94	12.86	6.22	−6.82
	JL2 (15 m)	171.97	4.00	37.88	4.25	6.75	1.82	49.90	12.65	6.20	−6.86
	JL2 (30 m)	174.86	4.46	37.80	4.19	7.13	1.82	51.36	13.34	6.04	−6.68
	JL3 (0 m)	173.90	4.01	37.33	4.12	7.23	1.94	49.60	12.98	6.23	−6.89
	JL3 (5 m)	167.17	8.54	38.07	4.26	6.69	1.80	46.62	12.59	6.10	−6.82
	JL3 (10 m)	169.09	4.29	37.96	4.37	6.38	1.76	49.28	12.14	5.77	−6.83
	JL3 (20 m)	174.86	4.04	37.79	4.25	6.58	1.81	48.92	12.28	6.03	−6.79
	JL3 (40 m)	171.01	4.69	39.22	4.32	7.21	1.85	39.10	13.41	6.08	−6.83
	JL4	167.17	4.21	38.37	4.19	7.41	1.95	28.44	13.45	6.19	−6.38
	JL5	169.09	4.55	37.37	4.47	7.33	1.95	48.45	12.81	6.14	−7.04
	JL6 (0 m)	165.25	4.76	38.13	4.38	7.25	1.95	48.83	12.70	5.98	−6.97
	JL6 (5 m)	169.09	4.51	38.46	4.54	6.55	1.77	47.72	12.06	5.80	−6.56
	JL6 (15 m)	171.01	4.84	38.36	4.17	7.54	2.02	47.53	12.87	6.10	−6.93
	JL7 (0 m)	169.09	4.84	38.57	4.44	7.18	1.96	48.80	12.44	5.91	−6.28
	JL7 (5 m)	171.01	4.56	38.82	4.46	7.02	1.86	51.56	12.49	5.97	−6.97
	JL7 (10 m)	167.17	4.51	38.22	4.31	7.63	2.04	51.43	12.90	6.09	−6.83
	JL7 (15 m)	171.01	4.77	38.43	4.46	7.20	1.93	64.15	12.51	5.99	−6.67
	JL8	167.17	4.48	38.09	4.24	7.88	2.08	47.12	13.07	6.22	−6.70
	JL9	167.17	6.73	37.78	4.88	8.47	2.12	50.97	12.06	6.10	−7.17
	JL10 (0 m)	169.09	6.32	38.01	4.84	8.72	2.20	48.06	11.90	6.26	−7.11
	JL10 (5 m)	169.09	6.49	38.19	4.77	8.94	2.24	51.95	12.12	6.30	−7.17
	JL10 (10 m)	168.13	6.15	38.58	4.85	7.88	1.99	54.01	11.64	6.19	−7.13
	JL11 (0 m)	165.25	6.41	38.06	4.96	7.83	1.98	49.76	11.45	5.85	−6.87
	JL11 (5 m)	167.17	6.65	38.22	5.00	8.75	2.24	49.39	12.13	6.20	−7.00
	JL11 (10 m)	167.17	4.34	38.36	4.93	6.82	1.79	42.53	9.97	5.12	−7.13
	JL11 (15 m)	167.17	5.88	38.69	4.98	9.03	2.32	51.22	12.41	6.43	−6.83
	JL12	143.15	43.06	35.68	4.27	18.70	2.35	55.46	10.05	4.94	−7.31
	JL13	165.25	7.65	39.38	5.58	8.84	2.24	49.41	11.69	5.90	−7.41
	JL14 (0 m)	172.94	12.01	43.61	7.03	11.54	2.58	56.35	11.59	6.43	−7.86
	JL14 (40 m)	171.97	12.64	44.60	6.95	13.57	2.93	53.74	12.48	6.65	−7.82
	JL15 (0 m)	171.97	11.39	44.22	7.13	12.89	2.84	57.74	12.35	6.64	−7.83
	JL15 (25 m)	171.97	11.56	44.48	7.11	13.04	2.89	54.96	12.59	6.70	−7.80
	JL15 (50 m)	171.01	11.36	44.10	7.06	12.98	2.83	55.99	12.44	6.65	−7.83
	JL16 (0 m)	171.97	10.92	44.45	6.78	11.08	2.47	57.09	11.76	6.32	−7.63
	JL16 (5 m)	172.94	9.26	36.44	5.93	12.70	2.84	53.80	12.48	6.68	−7.63
	JL16 (10 m)	173.90	11.06	42.74	6.93	12.90	3.15	53.36	12.27	6.60	−7.68
	JL16 (15 m)	172.94	11.21	44.18	6.96	12.08	2.70	57.00	12.14	6.61	−7.72
	JL16 (30 m)	172.94	11.06	44.59	7.20	11.51	2.58	53.58	11.62	6.35	−7.65
	JL17	169.09	11.29	44.00	7.16	11.54	2.58	56.35	11.59	6.43	−7.85
	Average	169.69	7.81	39.71	5.17	9.14	2.20	50.79	12.33	6.15	−7.10

diffusions and hydrodynamic conditions, which were under influences of reservoir types, capacities, water depths and regulation ways (Table 1). Based on the physiochemical stratification characteristics, Tingzikou Reservoir exhibited the features of a natural lake rather than a river, while Xinzheng Reservoir and Dongxiguan Reservoir belonged to a "Transitional type" between river–lake and Caojie Reservoir belonged to a total "Fluvial type".

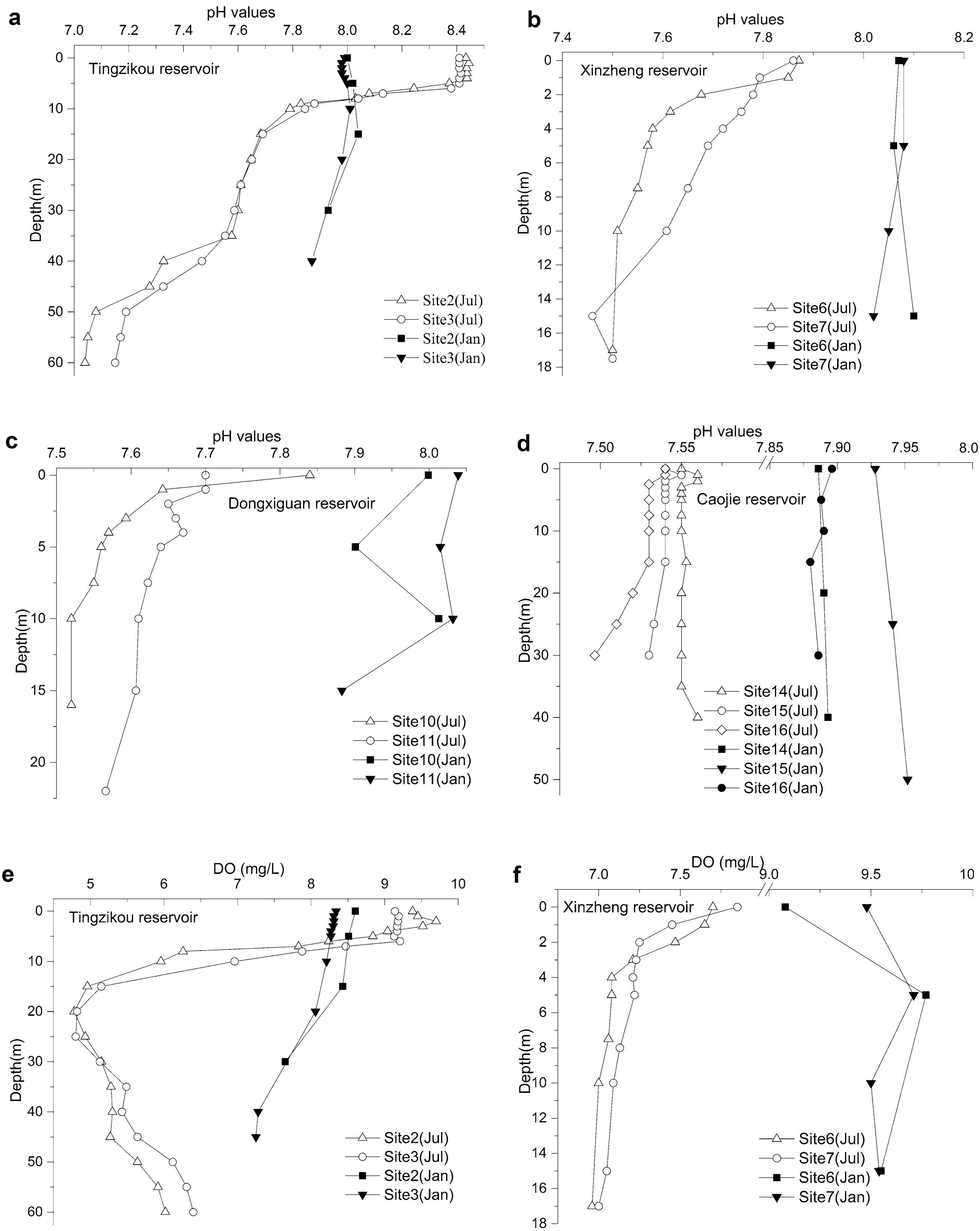

Fig. 4 Variations of the basic physical-chemical parameters in the water column

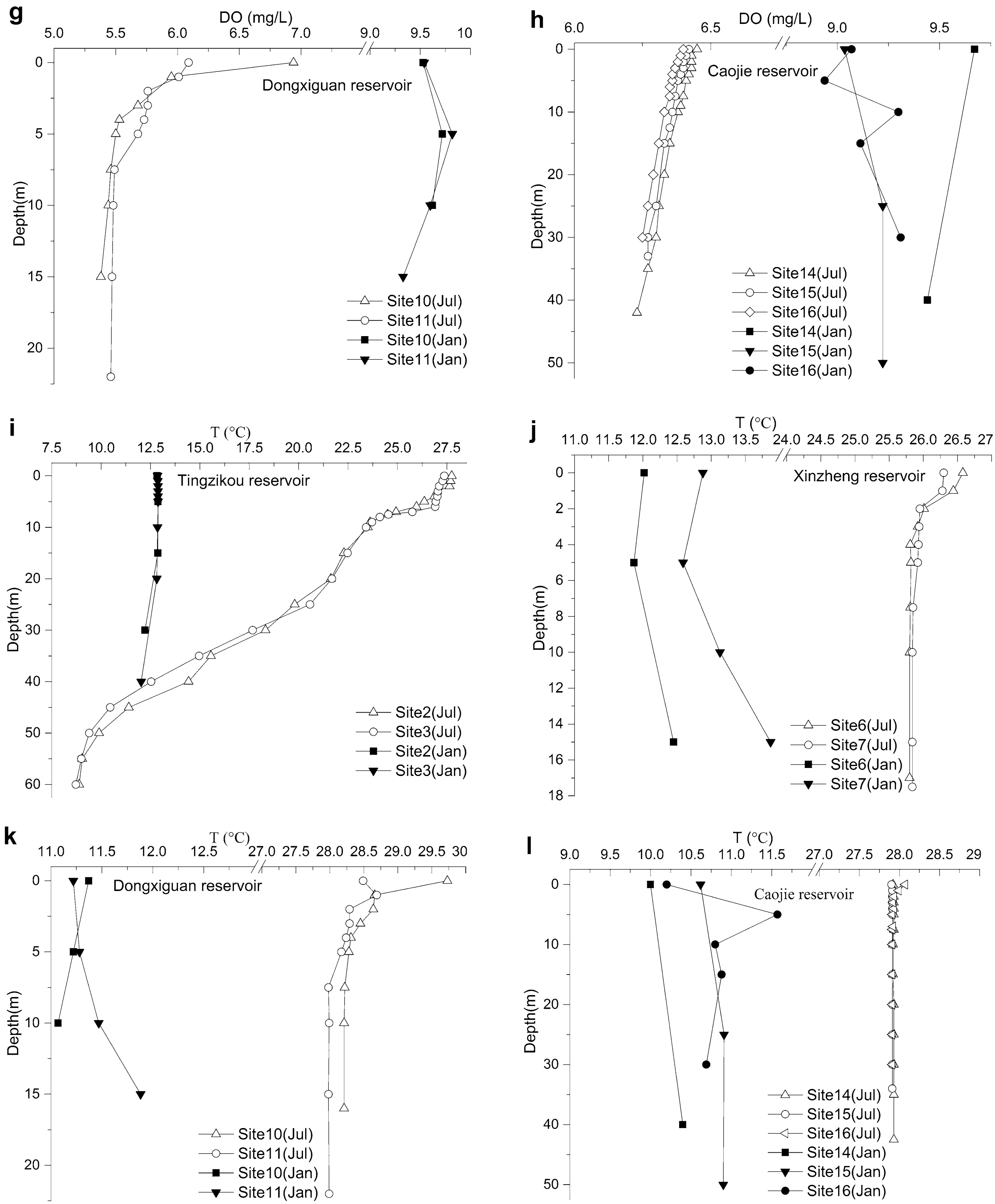

Fig. 4 continued

4.3 Spatiotemporal change characteristics of DIC concentrations

The pH values in study area ranged from 7 to 8.4, with an average of 7.61 (n = 80). The dissolved inorganic carbon in water body was dominated by HCO_3^-, which accounts for about 90% of the total DIC (CO_{2aq}, H_2CO_3, HCO_3^- and CO_3^{2-}). Thus HCO_3^- can be used to represent DIC in the aquatic system (Yu et al. 2008).

Different from riverine DIC, which are mainly affected by exogenous sources (soil CO_2, weathering of carbonate minerals and atmospheric CO_2), the DIC in reservoir water are affected by both exogenous and endogenous sources. The exogenous sources include riverine DIC and decompositions of organic matter which are carried by rivers, dissolution of atmospheric CO_2, etc., while endogenous sources include aquatic biological respiration, decomposition of biogenic organic matters, etc. The mainly lose ways of DIC in reservoir water include CO_2 degassing, carbonate precipitation or transfer to organic matters via photosynthesis, etc. (Yang et al. 1996a, 1996b; Ludwig et al. 1996; Liu et al. 2014).

4.3.1 Seasonal variation of DIC

The DIC concentrations were usually higher in winter than that in summer (except site12), both in surface and profiled water (Figs. 5a and 6). The DIC concentrations of surface water ranged from 1.81 to 2.65 mmol/L with an average of 2.35 mmol/L in summer, and ranged from 2.35 to 2.95 mmol/L with an average of 2.76 mmol/L in winter (Table 2). This result was consistent with other relevant research (Yu et al. 2008; Li et al. 2008a, 2008b, 2009), which can be explained by intensive dilution effects through the increase of water flow in summer (including precipitation, tributaries, surface and underground runoff). Besides, reduction of DIC concentration resulted from high temperatures, increasing light intensity and photosynthesis in summer. In winter, disappearance of thermal stratification lead to an adequately vertical exchange of water column, while hypolimnetic water with high HCO_3^- concentrations that were generated by organic matter decompositions and biological respiration were upwelling.

4.3.2 Spatial variation of DIC

Variation along the direction of flow In summer, the DIC concentrations of surface water decreased with tributaries imported, and inflow of Tingzikou Reservoir had minimum DIC concentration of 1.81 mmol/L (site 1) due to water dilution from the Bailong River (Fig. 5a). Then, the average concentration of DIC in surface water was increased to 2.19 mmol/L in Tingzikou Reservoir area due to the interception effect, and the outflow had maximum DIC concentration of 2.65 mmol/L (Fig. 5a). The DIC concentration in the inflow (2.58 mmol/L; Site 5) of Xinzheng Reservoir was slightly lower than the surface water in reservoir area (Average: 2.61 mmol/L), and continuously increased to 2.64 mmol/L of outflow (Fig. 5a). In summer, the DIC concentrations of surface water declined continuously from Dongxiguan Reservoir to Caojie Reservoir due to the obvious dilution effects of the Qujiang River and Fujiang River (Fig. 5a). The DIC concentration in the outflow of all reservoirs were higher than the surface water in front of the dam due to the released water generally keeping the signal of respiration C in hypolimnion (Fig. 5a).

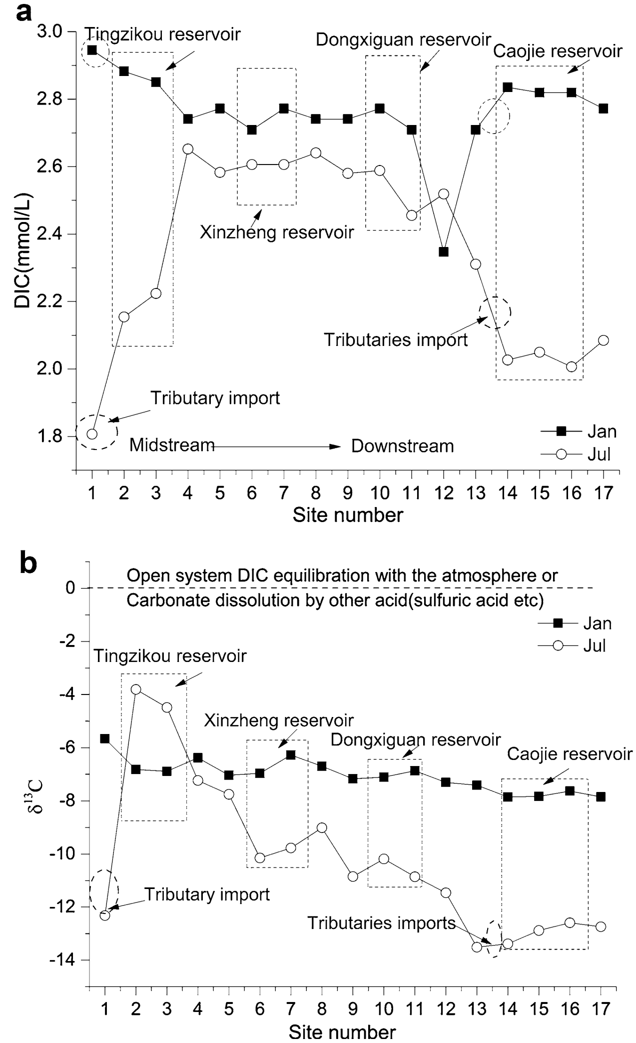

Fig. 5 Spatiotemporal variations of DIC concentrations (**a**) and $\delta^{13}C_{DIC}$ values (**b**) of surface water samples in the Jialing River

In winter, inflow of Tingzikou Reservoir had maximum DIC concentrations of 2.95 mmol/L due to Bailong River imported (Fig. 5a). After that, the DIC concentrations of

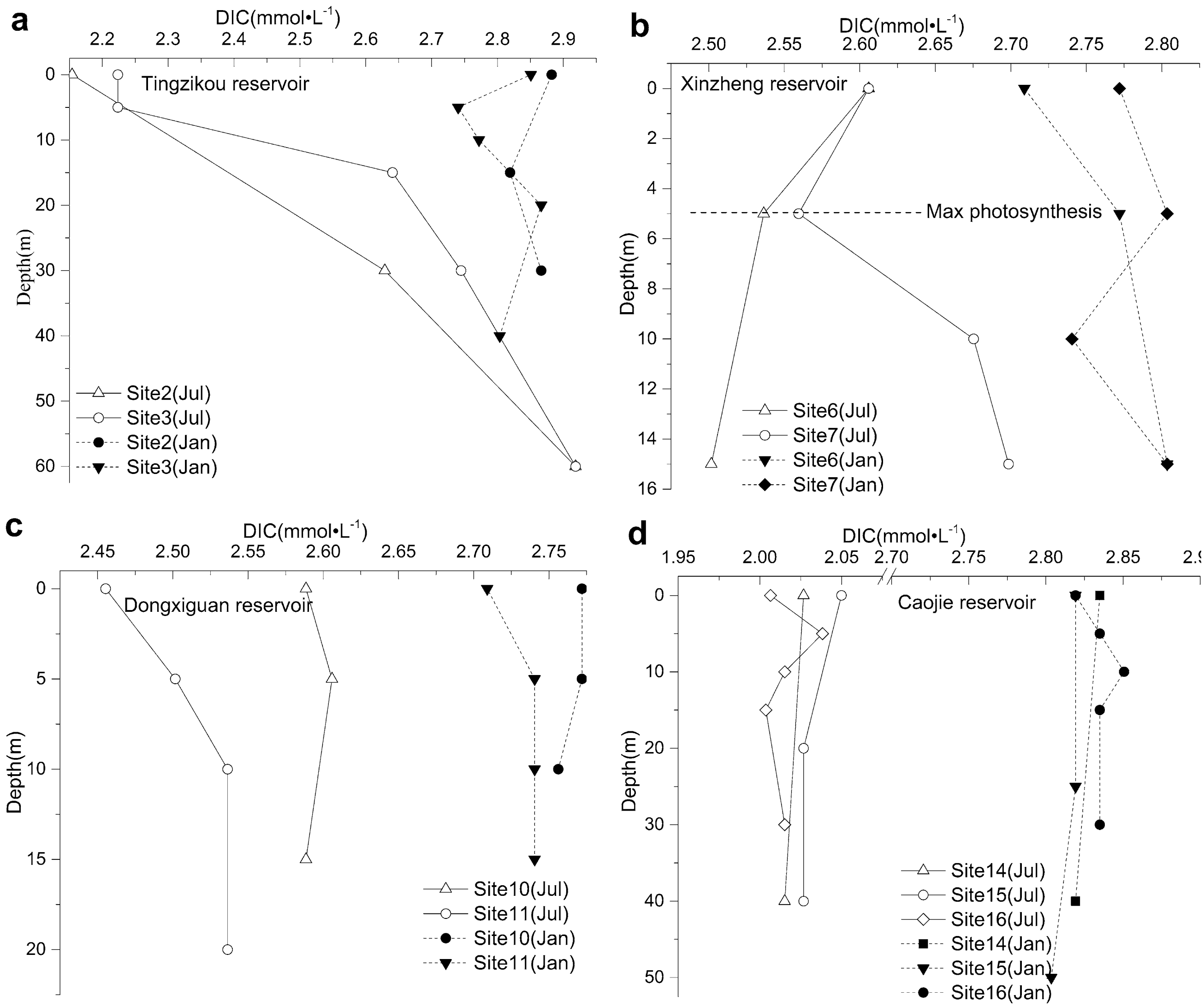

Fig. 6 Variations of DIC concentrations in the water column in cascade reservoirs

surface water changed slightly from Xinzheng Reservoir to Dongxiguan Reservoir, while outflow of Dongxiguan Reservoir had lowest DIC concentration of 2.35 mmol/L due to domestic wastewater (Fig. 5a). The DIC concentrations of surface water significantly increased from Dongxiguan Reservoir to Caojie Reservoir due to the Qujiang River and Fujiang River imported (Fig. 5a).

Variation along the water depth In summer, the DIC concentrations usually increased with water depth increasing, especially in Tingzikou Reservoir (Fig. 6). The average DIC concentrations of surface water (2.19 mmol/L) were lower than those of bottom water (2.92 mmol/L) in Tingzikou Reservoir during summer (Fig. 6). This can be explained by CO_{2aqu} (aqueous CO_2) absorption, which resulted from intense photosynthesis in euphotic zone of th epilimnion, whereas CO_2 released by decomposition of organic matters in water column and water–sediment interface would lead to higher DIC concentrations in hypolimnion. A similar trend was not obvious in Xinzheng Reservoir and Dongxiguan Reservoir due to shallow water depth (average depth: 17.5 m) and enhanced vertical exchanges of profiled water, which resulted from wide distributions of sand quarry activities and daily regulation way (Fig. 6). There were no obvious profile variations of DIC concentrations in Caojie Reservoir, which was also due to intensive turbulent kinetic energy and vertical diffusions that resulted from maximum inflow (tributaries and upstream water imported) and a shorter water residence time (daily/weekly regulation way). There were no significant profile variations of DIC concentrations in winter due to disappearance of thermal stratification and sufficient vertical exchanges of water column (Fig. 6).

4.4 Spatiotemporal variation characteristics of $\delta^{13}C_{DIC}$ values

4.4.1 Seasonal variation of $\delta^{13}C_{DIC}$

As a whole, higher $\delta^{13}C_{DIC}$ values of surface water in all studied reservoir (Tingzikou Reservoir excluded) were in winter (average:−7.05‰) than that in summer (average:−10.18‰), indicating more DIC were derived from soil CO_2 in rainy season due to high temperature and precipitations (Fig. 5b). The average $\delta^{13}C_{DIC}$ values of surface water in Tingzikou Reservoir were lower in winter (−6.86‰) than that in summer (−4.5‰), indicating that photosynthesis prevails in epilimnion of Tingzikou Reservoir in summer and enhancement of primary productivity which results in higher $\delta^{13}C_{DIC}$ values (Fig. 5b). This phenomenon was similar to reservoirs which had lacustrine features and natural lake. Such as the DIC concentrations of surface water in front of Hongjiadu dam which situated in upper reach of the Wujiang River ranged from 1.84 mmol/L (summer) to 2.28 mmol/L (winter) and the $\delta^{13}C_{DIC}$ values ranged from −8.3‰ in winter to −4.5‰ in summer (Yu et al. 2009). Yu et al. (2008) reported the average DIC concentrations of surface and profile water in cascade reservoirs in the Wujiang River were higher in winter (2.39 mmol/L) than those in summer (2.21 mmol/L), and the average $\delta^{13}C_{DIC}$ values were lower in winter (−9.08‰) than those in summer (−8.1‰). Li et al. (2009) reported the DIC concentrations in cascade reservoirs in the Maotiao River and found relatively high DIC concentration (2.67 mmol/L) combined with relatively negative $\delta^{13}C_{DIC}$ value (−9‰) in autumn, and relatively low DIC concentration (2.12 mmol/L) combined with positive $\delta^{13}C_{DIC}$ value (−8.6‰)in summer. Similar results also reported by Mybro and Shapley (2006) of the Jones Lake in Montana group lakes in US. Generally, the $\delta^{13}C_{DIC}$ values

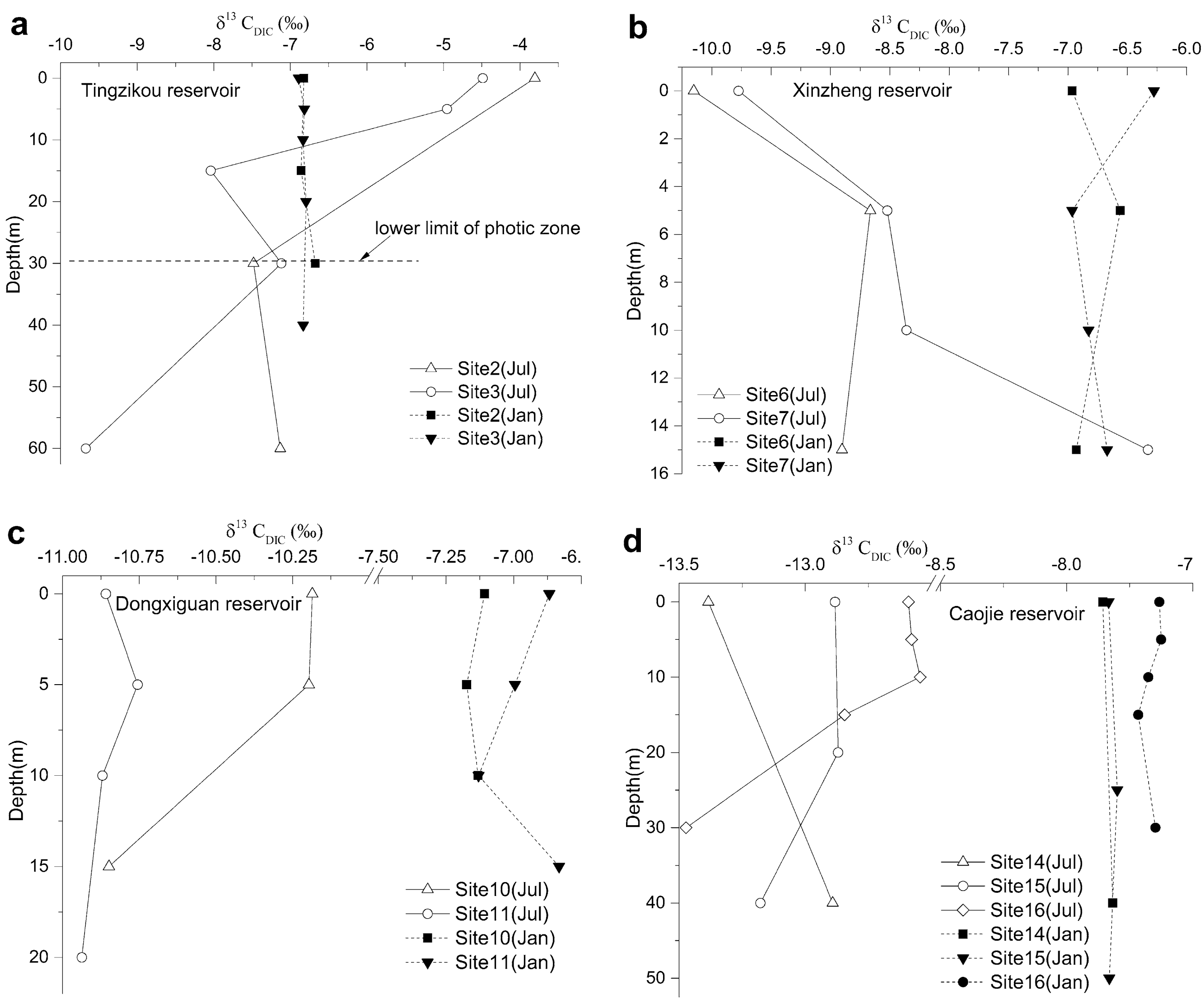

Fig. 7 Variations of $\delta^{13}C_{DIC}$ values in the water column in cascade reservoirs

of natural rivers tend to become more negative in summer than those in winter (Liu 2007; Jiao et al. 2008).

4.4.2 Spatial variation of $\delta^{13}C_{DIC}$

In summer, the $\delta^{13}C_{DIC}$ values of surface water tend to become more negative along the flow direction. This can be explained by the outflow water from the upstream reservoirs, as water with more negative $\delta^{13}C_{DIC}$ values will pour into the epilimnion of the downstream reservoirs, and this kind of spatial cumulative effect would cause the $\delta^{13}C_{DIC}$ values to become more negative and the DIC concentrations to become higher (Yu et al. 2008). The inflows of Tingzikou Reservoir and Caojie Reservoir had more negative $\delta^{13}C_{DIC}$ values of −12.32‰ and −13.51‰ in summer, respectively (Fig. 5b), indicating that inflows of Tingzikou Reservoir and Caojie Reservoir were influenced by the Bailong River, Fujiang River and Qujiang River water imported (Figs. 1, 5b). The similar variation characteristics appeared in the St. Lawrence River, while upstream and downstream of the St. Lawrence River were fed by Great Lakes and tributaries, respectively, and the downstream water had more negative $\delta^{13}C_{DIC}$ values rather than those upstream (Yang et al. 1996a, 1996b; Hélie et al 2002). In summer, surface water of Tingzikou Reservoir had maximum average $\delta^{13}C_{DIC}$ value of −4.15‰ (Fig. 5b), which could be attributed to photosynthesis of phytoplankton that utilized ^{12}C preferentially. 20‰–23‰ fractionation was produced in the synthesis process of organic matter by CO_{2aqu} (aqueous CO_2), which makes the $\delta^{13}C_{DIC}$ values of the body of water more positive (Buhl et al. 1991; Pawellek and Veizer. 1994; Hélie et al. 2002; Yu et al. 2008). Decomposition of organic matter in sediments will be accompanied with the extensive release of $^{12}CO_2$ into water column and then lead to $\delta^{13}C_{DIC}$ values decreasing. Thus, outflow came from hypolimnetic waters usually had more negative $\delta^{13}C_{DIC}$ values in summer, such as outflow of Tingzikou Reservoir, Dongxiguan Reservoir and Caojie Reservoir with a relatively negative $\delta^{13}C_{DIC}$ values of −7.24‰, −11.46‰ and −12.74‰, respectively (Fig. 5b). Except for Xinzheng Reservoir, inflow and outflow of reservoirs had more negative $\delta^{13}C_{DIC}$ values rather than surface water in reservoir area (Fig. 5b). Under the influence of outflow of Tingzikou Reservoir which had a relatively positive $\delta^{13}C_{DIC}$ value (−7.24‰, site 4), inflow of the Xinzheng Reservoir had a relatively positive $\delta^{13}C_{DIC}$ value (−7.76‰, site 5) rather than the surface water (average: −9.96‰) in reservoir area (Fig. 5b). Outflow of Xinzheng Reservoir had a relatively positive $\delta^{13}C_{DIC}$ value of −9.01‰ (Fig. 5b). There was no water draining of Xinzheng Reservoir during sampling period, while the downstream water was shallow and clear and intensive photosynthesis would result in higher $\delta^{13}C_{DIC}$ values.

Table 3 Pearson correlation coefficients among the water physicochemical parameters in the rainy and dry season of the "River-reservoir-River" system

Correlation coefficients	DIC	$Ca^{2+} + Mg^{2+}$	$Na^{+} + K^{+}$	Si	SO_4^{2-}	NO_3^{-}	Cl^{-}	$SO_4^{2-} + NO_3^{-} + Cl^{-}$	pH	DO	T(°C)
DIC (Jul)	1	0.958[a]	−0.035	−0.712[a]	0.673[a]	−0.218	−0.440[a]	0.432[a]	−0.263	−0.091	−0.456[a]
$\delta^{13}C_{DIC}$ (Jul)	0.535[a]	0.498[a]	−0.521[a]	−0.870[a]	0.741[a]	−0.680[a]	−0.788[a]	0.128	0.386[b]	0.376[b]	−0.273
DIC (Jan)	1	0.225	−0.302	0.559[a]	0.408[a]	0.202	−0.670[a]	−0.449[a]	−0.606[a]	−0.658[a]	−0.104
$\delta^{13}C_{DIC}$ (Jan)	0.047	−0.396[b]	−0.748[a]	−0.521[a]	−0.569[a]	−0.872[a]	−0.450[a]	−0.624[a]	0.109	−0.180	0.523[a]

Statistical results including values of surface and profiled water samples, n = 40, bold values represent correlation with significance, the same below

[a] Significance at the 0.01 probability level

[b] Significance at the 0.05 probability level

In a reservoir showing a lacustrine feature, the $\delta^{13}C_{DIC}$ values usually become more negative along with increasing water depth (Yu et al. 2008, 2009; Liu et al. 2014; Myrbo and Shaply 2006; Li et al. 2009), but there were different variation characteristics in different kinds of reservoirs in study area (Fig. 7). In rainy season, the average $\delta^{13}C_{DIC}$ value of surface water and bottom water samples collected from water column in Tingzikou Reservoir were −4.15‰ and −8.4‰ (Fig. 7); see first paragraph of Text 4.4.2 for specific reasons. The $\delta^{13}C_{DIC}$ values in front of Tingzikou dam (site 3) decreased firstly and lastly, increasing intermediately, while the $\delta^{13}C_{DIC}$ values in center of Tingzikou Reservoir (site 2) increased after decreasing firstly with water depth (Fig. 7). This may be attributed to the niche differentiation of different phytoplankton in euphotic layer, which exhibited different use patterns and intensities of ^{12}C. In rainy season, the average $\delta^{13}C_{DIC}$ values of Xinzheng Reservoir increased from surface water (−9.96‰) to hypolimnetic water (−7.62‰, Fig. 7). This may be attributed to frequently vertical exchange of profiled water in a shallow reservoir and upwelling of hypolimnetic water with more negative $\delta^{13}C_{DIC}$ values (Fig. 7). The average $\delta^{13}C_{DIC}$ values of Dongxiguan Reservoir were slightly decreasing along with increasing water depth (Fig. 7). The $\delta^{13}C_{DIC}$ values of reservoir water in front of the Caojie dam (site 16) and that in the center of Caojie Reservoir (site 15) trend to become slightly negative along with increasing water depth, and ranged from −12.59‰ to −13.47‰ and from −12.88‰ to −13.18‰ (Fig. 7), respectively.

4.5 Natural and anthropogenic effects on DIC concentrations and $\delta^{13}C_{DIC}$ values

The DIC concentrations and $\delta^{13}C_{DIC}$ values had significant correlations with most of the ions and physiochemical parameters ($p < 0.05$ or 0.01), indicating that these factors had close relations with the DIC concentrations and its isotopic compositions and representativeness of these indexes can be confirmed (Table 3). In summer, the DIC concentrations combined with $\delta^{13}C_{DIC}$ values had significant correlations with Ca^{2+}+Mg^{2+}, Si (calculated in SiO_2), SO_4^{2-} and Cl^- ($p < 0.01$), indicating the momentous influence of carbonate weathering on water chemistry, while anthropogenic inputs such as SO_4^{2-} and Cl^- have important effects on the DIC concentrations/isotopic compositions (Table 3). Meanwhile, the DIC concentrations were significantly affected by thermal stratification in summer (Table 3, Figs. 4 and 6). The study area is located in the Chengdu Plain, which has a large population and is developed industrial and agricultural. The Sichuan Basin area had undergone rapid development since the end of 1970s, and is now seriously affected by acid rain, which resulted from high sulfur-content coal combustion. Thus, sulfuric acid might play a relatively important role in carbonate weathering (Li et al. 2011). This process can lead to additions of both DIC concentrations and $\delta^{13}C_{DIC}$ values (Table 3). Chen et al. (2002) reported that SO_4^{2-} concentration had significantly positive correlation with the amount of coal-burning. The Cl^- ion of waters generally has three sources: atmospheric source, evaporate dissolution and anthropogenic source (mine, industry, city and agriculture). The study area is far away from the sea, thus very few Cl^- were derived from sea salt circulation (Bao et al. 2010), and there was basically no distribution of evaporate in the study area (Fig. 1). Therefore, Cl^- mainly was derived from anthropogenic inputs such as table and industrial salts, etc. Generally, additions of Cl^- and NO_3^- concentrations in waters body would significantly lower the DIC concentrations in the bodies of water (Table 3).

In winter, the DIC concentrations and $\delta^{13}C_{DIC}$ values had significant correlations with $SO_4^{2-} + NO_3^- + Cl^-$, Si (calculated in SiO_2), SO_4^{2-} and Cl^- ($p < 0.01$). All of these anthropogenic inputs would lower the $\delta^{13}C_{DIC}$ values (Table 3). Si (calculated in SiO_2) concentrations had a significantly negative correlation with $\delta^{13}C_{DIC}$ values, and there were a number of silicate rocks distributed in study area (Figs. 1 and 2). Thus, this phenomenon may be ascribed to decomposition and mineralization of biogenic silica in sediments (nutrient release) because of low solubility of silicate minerals, while DIC produced by this process had lower $\delta^{13}C_{DIC}$ values. Even very limited Si comes from chemical weathering of silicate and aluminosilicate rocks can lead to silicon accumulation in sediments due to physical sedimentation and bio-absorption (Liu et al. 2009).

Depending on the above interpretation, atmospheric inputs and weathering of evaporites had limited impacts on NO_3^- and Cl^-, while anthropogenic sources had important influences on both of them. Thus, correlation analyses were

Table 4 Pearson correlation coefficients among major anthropogenic ions in the rainy and dry season

Jul (n = 40)	Na^+	K^+	SO_4^{2-}	Cl^-	Jan (n = 40)	Na^+	K^+	SO_4^{2-}	Cl^-
Cl^-	0.751[a]	0.978[a]	−0.57[a]	1	Cl^-	0.852[a]	0.464[a]	0.158	1
NO_3^-	0.296	0.644[a]	−0.637[a]	0.561[a]	NO_3^-	0.702[a]	0.894[a]	0.850[a]	0.320[a]

[a] Significance at the 0.01 probability level

[b] Significance at the 0.05 probability level

conducted with reference of NO_3^- and Cl^- to estimate the extent of C dynamic influenced by anthropogenic inputs (Table 4). Results showed that Na^+, K^+, SO_4^{2-} were closely related to Cl^- and NO_3^-, especially in dry season ($p < 0.01$), indicating that all of these ions (Na^+, K^+, SO_4^{2-}, Cl^- and NO_3^-) were mainly derived from anthropogenic sources, and confirmed that the DIC concentrations and its isotopic compositions in the study area were affected by anthropogenic inputs significantly (Tables 3 and 4).

5 Conclusions

The solute compositions are dominated by carbonate weathering in the study area, while sulfuric acid may play a relatively important role in carbonate weathering. Besides, the water chemistry type can be mainly characterized as $HCO_3^- - Ca^{2+} \cdot Mg^{2+}$ type in the study area. The dissolved inorganic carbon cycle in the Jialing River had been remolded after dam building, and the studied cascade reservoirs in the Jialing River can be divided into three types (lacustrine type, transitional type and fluvial type) based on spatiotemporal variations of physiochemical stratification, DIC concentrations and carbon isotopic compositions. Tingzikou Reservoir exhibited lacustrine features because of obvious physiochemical stratification (e.g. T, pH and DO), DIC concentrations increasing and $\delta^{13}C_{DIC}$ values decreasing as the water depth increased in summer. Xinzheng Reservoir and Dongxiguan Reservoir had transitional features and Caojie Reservoir had "fluvial" features. The DIC concentrations and isotopic compositions were affected by anthropogenic inputs such as Na^+, K^+, Cl^-, SO_4^{2-} and NO_3^- which were most likely from rainwater, fertilizers, domestic wastewater or sulfide minerals oxidation. This study demonstrated that carbon biogeochemical cycling had been influenced by dam building in the Jialing River, and DIC concentrations combined with carbon isotopic compositions can be useful in tracing the anthropogenic pollutants and carbon biogeochemistry of damming rivers.

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