

Quantifying long-term changes in water quality and quantity of Euphrates and Tigris rivers, Turkey

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Abstract The Euphrates and Tigris watersheds originating from Turkey and passing through Syria and Iraq are one of the most important transboundary watersheds in the Middle East. Long-term data (1971 to 2002) from 14 stations over the Euphrates river and seven stations over the Tigris river were analyzed and compared using the nonparametric Kruskal–Wallis and Mann–Kendall trend tests, and box-and-whisker plots. The upper Euphrates river had significantly lower values of flow rate (FR), water temperature (WT), electrical conductivity (EC), Cl, and SO₄ than did the lower Euphrates river. The middle Euphrates river had significantly higher Na, K, HCO₃, Cl, sodium adsorption ratio (SAR), and boron (B) and lower EC and SO₄ than the lower Euphrates

river. The upper west Tigris river had higher EC, Ca + Mg, and SO₄ and lower FR, Na, and SAR than the lower Tigris river. The upper east Tigris river had higher HCO₃ and B and lower FR and WT than the lower Tigris river.

Keywords Euphrates · Tigris · Sustainable watershed management · Environmental monitoring

Introduction

Monitoring quality and quantity of water resources is of great importance to the sustainable development of nations (Smith et al. 1987; Charles et al. 2000; Hooper et al. 2001; Alcamo and Henrichs 2002; Babkin 2004). In Turkey, 500 water monitoring stations have been put into operation since the 1970s to collect monthly water data (Odemis and Evrendilek 2007, 2008). A hydrological observation network was established in Turkey to monitor the quality and quantity of water resources by the Survey Administration of Electric Power Resources (EIE) in 1935 and by the State Hydrological Works (TRSHW) in 1979. The hydrological network consists of 1,046 stations located along the main rivers and on the major tributaries of rivers in 26 watersheds. The areal coverage of Turkey's watersheds ranges from 6,907 km² (Little Menderes) to 127,304 km²

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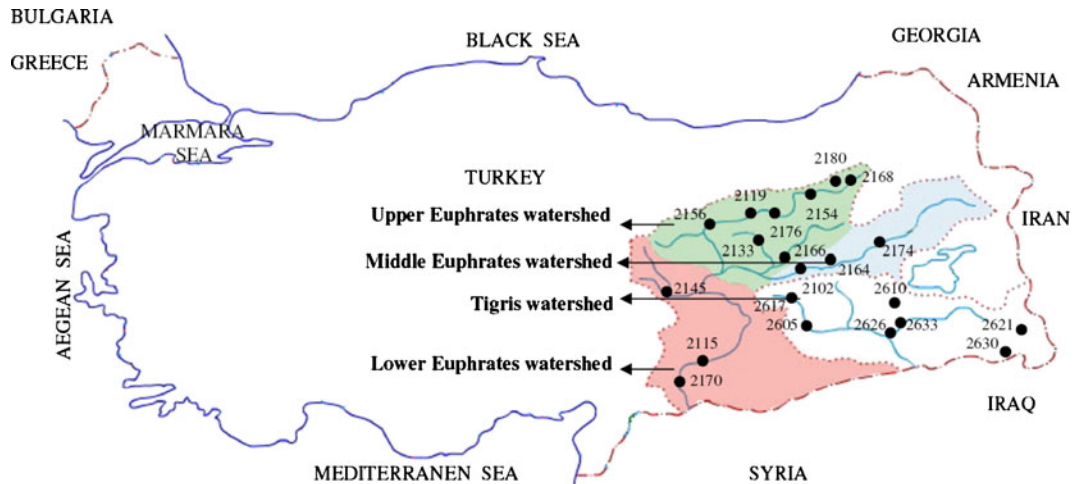


Fig. 1 Location of upper, middle, and lower Euphrates and Tigris watersheds and their monitoring stations in Turkey (see Table 1 for names and data range of the stations)

(Euphrates) (Odemis and Evrendilek 2007, 2008). Globally, 214 river watersheds are shared by more than one country; 155 of these are shared between two countries, 36 among three countries, and the remaining 23 among four to 12 countries (UNEP 1992). About 50 countries have more than 75% of their total land area falling within transboundary watersheds, and an estimated 35–40% of the world population lives in transboundary watersheds (Postel 2000).

This study aims at exploring long-term changes in water quality and quantity of the Euphrates and Tigris rivers, which originate in Turkey, flow through Syria and Iraq, and discharge into the Persian Gulf in Iraq. The Euphrates and Tigris watersheds have strategic importance for Turkey in that the most important national investment called GAP (Southeastern Anatolian Project) is located in the Euphrates watershed, with several irrigation and energy related sub-projects (with 13 dams and 1,656,627 ha of irrigated land) (Tekinel et al. 1989).

Materials and methods

The Euphrates and Tigris watersheds have approximately one third of Turkish total water

potential and occupy one fourth of the total area of Turkey (Fig. 1). Having a drainage area of 127,304 km² (16.2% of Turkish land area), the Euphrates watershed is the largest one in Turkey. Mean annual precipitation potential was

Table 1 Names and data range of the stations for the Euphrates and Tigris rivers

River name	Station number	Station name	Data range
Euphrates	2102	Murat	1974–2002
Euphrates	2115	Goksu	1989–2002
Euphrates	2119	Euphrates 1	1971–2002
Euphrates	2133	Munzur	1974–1994
Euphrates	2145	Tohma	1990–2002
Euphrates	2154	Karasu	1988–2002
Euphrates	2156	Euphrates 2	1992–2002
Euphrates	2164	Goyluk	1987–2002
Euphrates	2166	Peri	1984–2002
Euphrates	2168	Dumlu 1	1988–1997
Euphrates	2170	Euphrates 3	1984–1999
Euphrates	2174	Murat 2	1987–2002
Euphrates	2176	Tacik	1984–2002
Euphrates	2180	Dumlu 2	1997–2002
Tigris	2605	Tigris 1	1973–2001
Tigris	2610	Tigris 2	1987–2002
Tigris	2617	Bitlis creek	1973–1997
Tigris	2621	Zap water 1	1974–2002
Tigris	2626	Botan 1	1984–1996
Tigris	2630	Zap water 2	1986–2002
Tigris	2633	Botan 2	1997–2002

calculated to be approximately 74.1 billion cubic meters, with mean annual water flow being estimated at 31.5 billion cubic meters. Mean annual runoff in the watershed is 262 mm with mean annual precipitation of 540 mm; 16.8% of the entire Turkish runoff occurs in the Euphrates watershed. The watershed has 11 branches at different elevations, and each branch has a water monitoring station. The principal component of the river is the Euphrates–Belkizkoy stream (340 m a.s.l.). Other branches are: Murat river (859 m a.s.l.); Goksu stream (397 m a.s.l.); Euphrates–Bagistas (865 m a.s.l.); Kemahbogazi stream (1,123 m a.s.l.); Munzur stream (875 m a.s.l.); Tohma stream

(935 m a.s.l.); Karasu (1675 m a.s.l.); Goynuk creek (998 m a.s.l.); Peri stream (847 m a.s.l.); Dumlu stream (2,000 m a.s.l.); Murat–Akkonak stream (1,285 m a.s.l.); Tacik creek (1,225 m a.s.l.); Dumlu creek–Yesildere (1,935 m a.s.l.) (EIE 2002; TRSHW 2002) (Table 1).

The Tigris watershed has a total drainage area of approximately 57,614 km² (7.39% of the Turkish land area). Mean annual precipitation potential in the Tigris watershed was estimated at 46.9 billion cubic meters, with mean annual water flow of 21.2 billion cubic meters. Mean annual runoff and mean annual precipitation are 471 and 807 mm, respectively; 12.9% of the entire Turkish

Table 2 Mann–Kendall trend results (at $P < 0.05$) for water properties from 13 stations of the Euphrates river with a monitoring period of ≥ 10 years

Station	Period (year)	FR (m ³ s ⁻¹)	WT (°C)	pH	EC (μmhos cm ⁻¹)	Na (meq L ⁻¹)	K (meq L ⁻¹)
2102	22	No trend	No trend	Increasing	No trend	No trend	Increasing
2115	14	Increasing	No trend	Increasing	No trend	Increasing	No trend
2119	25	No trend	No trend	Increasing	No trend	Increasing	Increasing
2133	14	No trend	Decreasing	Increasing	No trend	Increasing	No trend
2145	13	No trend	Increasing	Increasing	No trend	No trend	No trend
2154	15	No trend	Increasing	Increasing	No trend	No trend	No trend
2156	11	No trend	No trend	Increasing	No trend	No trend	No trend
2164	16	No trend	No trend	Increasing	No trend	No trend	No trend
2166	19	Decreasing	No trend	Increasing	Decreasing	No trend	No trend
2168	10	No trend	No trend	No trend	No trend	No trend	No trend
2170	16	No trend	Decreasing	No trend	No trend	No trend	No trend
2174	16	Decreasing	No trend	Increasing	Increasing	Increasing	Increasing
2176	19	No trend	Increasing	Increasing	Increasing	No trend	Decreasing
Station	Ca+Mg (meq L ⁻¹)	CO ₃ (meq L ⁻¹)	HCO ₃ (meq L ⁻¹)	Cl (meq L ⁻¹)	SO ₄ (meq L ⁻¹)	SAR	B (mg L ⁻¹)
2102	No trend	Increasing	Decreasing	Increasing	No trend	Increasing	No trend
2115	No trend	No trend	Decreasing	No trend	Increasing	Increasing	No trend
2119	No trend	Increasing	No trend	No trend	No trend	Increasing	No trend
2133	No trend	Increasing	No trend	No trend	No trend	Increasing	Decreasing
2145	No trend	No trend	No trend	No trend	Increasing	No trend	No trend
2154	No trend	No trend	No trend	No trend	Increasing	No trend	No trend
2156	No trend	No trend	No trend	No trend	No trend	No trend	Increasing
2164	No trend	No trend	No trend	No trend	Increasing	No trend	No trend
2166	Decreasing	No trend	Decreasing	No trend	No trend	No trend	No trend
2168	No trend	No trend	No trend	No trend	No trend	No trend	No trend
2170	No trend	No trend	Increasing	No trend	Decreasing	No trend	No trend
2174	No trend	Decreasing	Increasing	Increasing	No trend	Increasing	No trend
2176	Increasing	No trend	No trend	No trend	Increasing	No trend	No trend

See Table 1 for names and data range of the stations

FR flow rate; WT water temperature; EC electrical conductivity; SAR sodium adsorption ratio

Table 3 Kruskal–Wallis test results for significant differences in six water variables among 14 stations over the Euphrates river

FR	P value	WT	P value	pH	P value	EC	P value	Na	P value	K	P value
2170 vs. 2176	0.0001	2115 vs. 2168	0.0001	2168 vs. 2174	0.0001	2119 vs. 2168	0.0001	2115 vs. 2174	0.0001	2154 vs. 2176	0.0001
2102 vs. 2176	0.0001	2115 vs. 2176	0.0001	2154 vs. 2168	0.0001	2115 vs. 2119	0.0001	2133 vs. 2174	0.0001	2174 vs. 2176	0.0001
2168 vs. 2170	0.0001	2115 vs. 2154	0.0001	2133 vs. 2174	0.0001	2119 vs. 2164	0.0001	2102 vs. 2115	0.0001	2133 vs. 2154	0.0001
2102 vs. 2168	0.0001	2115 vs. 2119	0.0001	2133 vs. 2154	0.0001	2168 vs. 2174	0.0001	2102 vs. 2133	0.0001	2115 vs. 2154	0.0001
2154 vs. 2170	0.0001	2168 vs. 2170	0.0001	2156 vs. 2168	0.0001	2115 vs. 2174	0.0001	2174 vs. 2176	0.0001	2133 vs. 2174	0.0001
2145 vs. 2170	0.0001	2145 vs. 2168	0.0001	2119 vs. 2168	0.0001	2164 vs. 2174	0.0001	2168 vs. 2174	0.0001	2115 vs. 2174	0.0001
2174 vs. 2176	0.0001	2102 vs. 2168	0.0001	2133 vs. 2156	0.0001	2119 vs. 2180	0.0001	2115 vs. 2154	0.0001	2102 vs. 2176	0.0001
2170 vs. 2180	0.0001	2170 vs. 2176	0.0001	2119 vs. 2133	0.0001	2174 vs. 2180	0.0001	2102 vs. 2176	0.0001	2164 vs. 2176	0.0001
2156 vs. 2176	0.0001	2115 vs. 2180	0.0001	2168 vs. 2176	0.0001	2119 vs. 2176	0.0001	2133 vs. 2154	0.0001	2102 vs. 2133	0.0001
2168 vs. 2174	0.0001	2154 vs. 2170	0.0001	2164 vs. 2168	0.0001	2102 vs. 2168	0.0001	2102 vs. 2168	0.0001	2133 vs. 2164	0.0001
2164 vs. 2170	0.0001	2145 vs. 2176	0.0001	2133 vs. 2176	0.0003	2174 vs. 2176	0.0001	2174 vs. 2180	0.0001	2102 vs. 2115	0.0001
2102 vs. 2154	0.0001	2102 vs. 2176	0.0001	2145 vs. 2168	0.0003	2102 vs. 2115	0.0001	2166 vs. 2174	0.0001	2115 vs. 2164	0.0001
2156 vs. 2168	0.0001	2166 vs. 2168	0.0001	2102 vs. 2168	0.0004	2119 vs. 2166	0.0001	2115 vs. 2119	0.0001	2154 vs. 2156	0.0001
2102 vs. 2145	0.0001	2164 vs. 2168	0.0001	2133 vs. 2164	0.0008	2154 vs. 2168	0.0001	2154 vs. 2168	0.0001	2145 vs. 2154	0.0001
2102 vs. 2180	0.0001	2145 vs. 2154	0.0001	2166 vs. 2168	0.001	2156 vs. 2168	0.0001	2119 vs. 2133	0.0001	2119 vs. 2154	0.0001
2119 vs. 2176	0.0001	2102 vs. 2154	0.0001	2133 vs. 2145	0.0017	2119 vs. 2133	0.0001	2154 vs. 2176	0.0001	2156 vs. 2174	0.0001
2115 vs. 2170	0.0001	2119 vs. 2170	0.0001	2102 vs. 2133	0.002	2102 vs. 2164	0.0001	2102 vs. 2180	0.0001	2145 vs. 2174	0.0001
2102 vs. 2164	0.0001	2115 vs. 2133	0.0001			2166 vs. 2174	0.0001	2102 vs. 2166	0.0001	2119 vs. 2174	0.0001
2174 vs. 2180	0.0001	2168 vs. 2174	0.0001			2115 vs. 2154	0.0001	2154 vs. 2180	0.0001	2166 vs. 2176	0.0001
2154 vs. 2174	0.0001	2166 vs. 2176	0.0001			2145 vs. 2168	0.0001	2119 vs. 2168	0.0001	2154 vs. 2168	0.0001
2156 vs. 2180	0.0001	2164 vs. 2176	0.0001			2133 vs. 2174	0.0001	2119 vs. 2176	0.0001	2154 vs. 2180	0.0001
2119 vs. 2168	0.0001	2119 vs. 2145	0.0001			2115 vs. 2156	0.0001	2164 vs. 2174	0.0001	2170 vs. 2176	0.0001

2145 vs. 2174	0.0001	2102 vs. 2119	0.0001	2154 vs. 2164	0.0001	2170 vs. 2174	0.0001	2174 vs. 2180	0.0001
2154 vs. 2156	0.0001	2154 vs. 2166	0.0001	2156 vs. 2164	0.0001	2154 vs. 2166	0.0001	2168 vs. 2174	0.0001
2133 vs. 2176	0.0001	2154 vs. 2164	0.0001	2102 vs. 2180	0.0001	2115 vs. 2156	0.0001	2133 vs. 2166	0.0001
2145 vs. 2156	0.0001	2170 vs. 2180	0.0001	2115 vs. 2145	0.0001	2119 vs. 2180	0.0001	2154 vs. 2170	0.0001
2166 vs. 2176	0.0001	2174 vs. 2176	0.0001	2156 vs. 2180	0.0001	2115 vs. 2145	0.0001	2115 vs. 2166	0.0002
2133 vs. 2168	0.0001	2156 vs. 2168	0.0001	2154 vs. 2180	0.0001	2133 vs. 2156	0.0001	2154 vs. 2166	0.0002
2166 vs. 2168	0.0001	2145 vs. 2180	0.0001	2145 vs. 2164	0.0001	2133 vs. 2145	0.0001	2119 vs. 2176	0.0002
2166 vs. 2170	0.0001	2154 vs. 2174	0.0001	2119 vs. 2170	0.0001	2102 vs. 2164	0.0001	2156 vs. 2164	0.0003
2164 vs. 2174	0.0001	2102 vs. 2180	0.0001	2145 vs. 2180	0.0001	2156 vs. 2168	0.0001	2102 vs. 2156	0.0005
2119 vs. 2170	0.0001	2119 vs. 2166	0.0001	2170 vs. 2174	0.00010	2145 vs. 2168	0.0001	2133 vs. 2170	0.0005
2102 vs. 2115	0.0001	2119 vs. 2164	0.0001	2102 vs. 2176	0.0001	2102 vs. 2170	0.0001	2115 vs. 2170	0.0006
2156 vs. 2164	0.0001	2166 vs. 2180	0.0003	2156 vs. 2176	0.0002	2156 vs. 2180	0.0001	2170 vs. 2174	0.0006
2119 vs. 2180	0.0001	2164 vs. 2180	0.0004	2154 vs. 2176	0.0002	2119 vs. 2166	0.0002	2145 vs. 2164	0.0006
2133 vs. 2180	0.0002	2156 vs. 2176	0.0006	2102 vs. 2133	0.0004	2145 vs. 2180	0.0002	2166 vs. 2174	0.0008
2133 vs. 2170	0.0003	2133 vs. 2170	0.0006	2102 vs. 2166	0.0005	2156 vs. 2176	0.0003	2102 vs. 2145	0.001
2166 vs. 2180	0.0004	2119 vs. 2174	0.0007	2168 vs. 2170	0.0006	2154 vs. 2164	0.0003	2119 vs. 2164	0.0017
2119 vs. 2154	0.0005	2154 vs. 2156	0.0009	2133 vs. 2156	0.0007	2145 vs. 2176	0.0004		
2119 vs. 2145	0.0006	2174 vs. 2180	0.0011	2145 vs. 2176	0.0008	2115 vs. 2170	0.0006		
2115 vs. 2174	0.0009	2133 vs. 2145	0.0015	2133 vs. 2154	0.001	2154 vs. 2170	0.0007		
2115 vs. 2156	0.0015	2115 vs. 2156	0.0017	2156 vs. 2166	0.0011	2133 vs. 2170	0.0011		
2133 vs. 2154	0.0017	2115 vs. 2174	0.0019	2154 vs. 2166	0.0016	2115 vs. 2164	0.0012		
2102 vs. 2166	0.0018					2145 vs. 2174	0.0018		
2133 vs. 2145	0.0019								
2115 vs. 2168	0.0021								

See Table 1 for names and data range of the stations
FR flow rate; *WT* water temperature; *EC* electrical conductivity

Table 4 Kruskal–Wallis test results for significant differences in seven water variables among 14 stations over the Euphrates river

Ca+Mg	p value	CO ₃	p value	HCO ₃	p value	Cl	p value	SO ₄	p value	SAR	p value	Boron	p value
2119 vs. 2164	0.0001	2154 vs. 2168	0.0001	2119 vs. 2168	0.0001	2174 vs. 2176	0.0001	2145 vs. 2168	0.0001	2133 vs. 2174	0.0001	2115 vs. 2154	0.0001
2119 vs. 2168	0.0001	2168 vs. 2174	0.0001	2115 vs. 2119	0.0001	2115 vs. 2174	0.0001	2156 vs. 2168	0.0001	2115 vs. 2174	0.0001	2145 vs. 2154	0.0001
2115 vs. 2119	0.0001	2133 vs. 2154	0.0001	2119 vs. 2170	0.0001	2168 vs. 2174	0.0001	2145 vs. 2164	0.0001	2102 vs. 2133	0.0001	2154 vs. 2176	0.0001
2119 vs. 2180	0.0001	2133 vs. 2174	0.0001	2119 vs. 2164	0.0001	2102 vs. 2176	0.0001	2115 vs. 2145	0.0001	2102 vs. 2115	0.0001	2154 vs. 2166	0.0001
2156 vs. 2164	0.0001	2119 vs. 2168	0.0001	2119 vs. 2180	0.0001	2102 vs. 2115	0.0001	2156 vs. 2164	0.0001	2174 vs. 2176	0.0001	2115 vs. 2174	0.0001
2156 vs. 2168	0.0001	2115 vs. 2154	0.0001	2154 vs. 2168	0.0001	2102 vs. 2168	0.0001	2115 vs. 2156	0.0001	2133 vs. 2154	0.0001	2102 vs. 2115	0.0001
2102 vs. 2119	0.0001	2119 vs. 2133	0.0001	2168 vs. 2174	0.0001	2174 vs. 2180	0.0001	2145 vs. 2180	0.0001	2115 vs. 2154	0.0001	2145 vs. 2174	0.0001
2145 vs. 2164	0.0001	2115 vs. 2174	0.0001	2119 vs. 2176	0.0001	2133 vs. 2174	0.0001	2119 vs. 2168	0.0001	2102 vs. 2176	0.0001	2154 vs. 2170	0.0001
2145 vs. 2168	0.0001	2154 vs. 2180	0.0001	2154 vs. 2180	0.0001	2102 vs. 2180	0.0001	2156 vs. 2180	0.0001	2168 vs. 2174	0.0001	2154 vs. 2180	0.0001
2119 vs. 2170	0.0001	2174 vs. 2180	0.0001	2115 vs. 2154	0.0001	2164 vs. 2174	0.0001	2168 vs. 2170	0.0001	2166 vs. 2174	0.0001	2174 vs. 2176	0.0001
2115 vs. 2156	0.0001	2115 vs. 2119	0.0001	2119 vs. 2145	0.0001	2166 vs. 2174	0.0001	2119 vs. 2164	0.0001	2154 vs. 2176	0.0001	2115 vs. 2119	0.0001
2156 vs. 2180	0.0001	2119 vs. 2180	0.0001	2154 vs. 2170	0.0001	2102 vs. 2133	0.0001	2115 vs. 2119	0.0001	2102 vs. 2168	0.0001	2154 vs. 2168	0.0001
2115 vs. 2145	0.0001	2156 vs. 2168	0.0001	2102 vs. 2168	0.0001	2115 vs. 2119	0.0001	2102 vs. 2145	0.0001	2119 vs. 2133	0.0001	2166 vs. 2174	0.0001
2145 vs. 2180	0.0001	2102 vs. 2168	0.0001	2156 vs. 2168	0.0001	2119 vs. 2176	0.0001	2164 vs. 2170	0.0001	2115 vs. 2119	0.0001	2102 vs. 2145	0.0001
2119 vs. 2166	0.0001	2102 vs. 2133	0.0002	2154 vs. 2164	0.0001	2102 vs. 2164	0.0001	2115 vs. 2170	0.0001	2174 vs. 2180	0.0001	2102 vs. 2176	0.0001
2133 vs. 2168	0.0001	2133 vs. 2156	0.0002	2174 vs. 2180	0.0001	2119 vs. 2168	0.0001	2102 vs. 2156	0.0001	2102 vs. 2166	0.0001	2154 vs. 2156	0.0002
2133 vs. 2164	0.0001	2168 vs. 2176	0.0003	2119 vs. 2166	0.0001	2102 vs. 2166	0.0001	2119 vs. 2180	0.0001	2154 vs. 2168	0.0001	2119 vs. 2145	0.0002
2168 vs. 2176	0.0001	2164 vs. 2168	0.0004	2119 vs. 2133	0.0001	2119 vs. 2180	0.0001	2170 vs. 2180	0.0001	2102 vs. 2180	0.0001	2154 vs. 2164	0.0003
2119 vs. 2154	0.0001	2145 vs. 2154	0.0004	2115 vs. 2174	0.0001	2145 vs. 2168	0.0001	2168 vs. 2176	0.0001	2133 vs. 2145	0.0001	2133 vs. 2154	0.0003
2164 vs. 2176	0.0001	2156 vs. 2180	0.0005	2156 vs. 2180	0.0001	2115 vs. 2145	0.0001	2145 vs. 2174	0.0001	2115 vs. 2145	0.0001	2102 vs. 2166	0.0004
2168 vs. 2174	0.0001	2145 vs. 2174	0.0007	2170 vs. 2174	0.0001	2145 vs. 2176	0.0001	2166 vs. 2168	0.0001	2154 vs. 2166	0.0001	2119 vs. 2176	0.0008
2102 vs. 2156	0.0001	2102 vs. 2180	0.0009	2166 vs. 2168	0.0001	2145 vs. 2180	0.0001	2145 vs. 2154	0.0001	2133 vs. 2156	0.0001	2174 vs. 2180	0.0001

2164 vs. 2174	0.0001	2133 vs. 2176	0.0009	2102 vs. 2180	0.0001	2154 vs. 2168	0.0001	2156 vs. 2174	0.0001	2115 vs. 2156	0.0001	2115 vs. 2164	0.0012
2156 vs. 2170	0.0001	2133 vs. 2164	0.0013	2164 vs. 2174	0.0001	2115 vs. 2154	0.0001	2154 vs. 2156	0.0001	2170 vs. 2174	0.0001	2119 vs. 2154	0.0017
2133 vs. 2180	0.0001	2115 vs. 2156	0.0015	2115 vs. 2156	0.0001	2170 vs. 2174	0.0001	2133 vs. 2168	0.0001	2154 vs. 2180	0.0001	2170 vs. 2174	0.0002
2115 vs. 2133	0.0001	2154 vs. 2166	0.0019	2102 vs. 2115	0.0001	2154 vs. 2180	0.0001	2102 vs. 2119	0.0001	2119 vs. 2176	0.0001	2115 vs. 2133	0.0021
2119 vs. 2176	0.0001	2166 vs. 2168	0.0002	2102 vs. 2119	0.0001	2154 vs. 2176	0.0001	2164 vs. 2176	0.0001	2164 vs. 2174	0.0001	2168 vs. 2174	0.0021
2119 vs. 2174	0.0001	2154 vs. 2170	0.0021	2145 vs. 2154	0.0001	2119 vs. 2133	0.0001	2176 vs. 2180	0.0001	2102 vs. 2170	0.0001		
2176 vs. 2180	0.0001	2102 vs. 2115	0.0021	2154 vs. 2176	0.0002	2119 vs. 2164	0.0001	2115 vs. 2176	0.0001	2119 vs. 2168	0.0001		
2102 vs. 2145	0.0001			2156 vs. 2170	0.0002	2156 vs. 2168	0.0001	2102 vs. 2170	0.0001	2133 vs. 2164	0.0001		
2166 vs. 2168	0.0001			2102 vs. 2170	0.0002	2102 vs. 2170	0.0001	2166 vs. 2180	0.0001	2115 vs. 2164	0.0001		
2154 vs. 2168	0.0001			2133 vs. 2168	0.0003	2156 vs. 2180	0.0001	2164 vs. 2166	0.0001	2145 vs. 2176	0.0001		
2145 vs. 2170	0.0001			2166 vs. 2180	0.0004	2119 vs. 2166	0.0001	2115 vs. 2166	0.0002	2102 vs. 2164	0.0001		
2174 vs. 2180	0.0002			2168 vs. 2176	0.0005	2133 vs. 2145	0.0001	2133 vs. 2180	0.0002	2156 vs. 2176	0.0002		
2115 vs. 2176	0.0002			2156 vs. 2164	0.0008	2115 vs. 2156	0.0001	2145 vs. 2166	0.0002	2133 vs. 2170	0.0002		
2164 vs. 2166	0.0003			2102 vs. 2164	0.0012	2145 vs. 2164	0.0002	2133 vs. 2164	0.0004	2115 vs. 2170	0.0003		
2156 vs. 2166	0.0003			2133 vs. 2180	0.0018	2156 vs. 2176	0.0002	2115 vs. 2133	0.0005	2145 vs. 2168	0.0004		
2154 vs. 2164	0.0004					2145 vs. 2166	0.0004	2156 vs. 2166	0.0006	2119 vs. 2180	0.0004		
2115 vs. 2174	0.0007					2133 vs. 2154	0.0006	2133 vs. 2145	0.0008	2154 vs. 2170	0.0004		
2154 vs. 2156	0.0011					2170 vs. 2180	0.0008	2145 vs. 2176	0.0008	2156 vs. 2168	0.0007		
2154 vs. 2180	0.0012					2168 vs. 2170	0.0009	2154 vs. 2168	0.0011	2119 vs. 2174	0.0008		
2166 vs. 2180	0.0013					2154 vs. 2164	0.0017	2133 vs. 2156	0.0011	2119 vs. 2166	0.001		
2102 vs. 2168	0.0013					2115 vs. 2170	0.0018	2168 vs. 2174	0.0013	2154 vs. 2164	0.0012		
						2156 vs. 2174	0.002	2156 vs. 2176	0.0013	2145 vs. 2180	0.0013		
								2170 vs. 2174	0.0019	2156 vs. 2180	0.0019		
								2119 vs. 2174	0.0019				

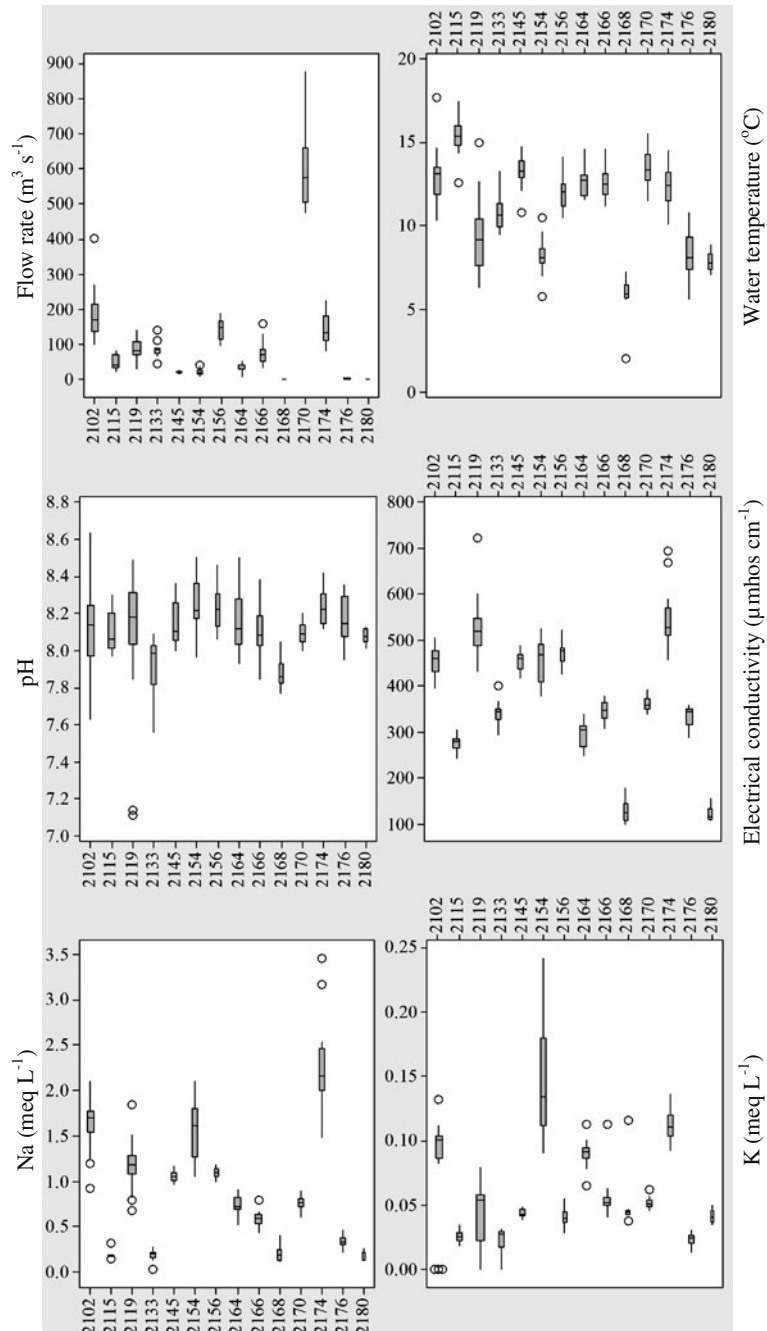
See Table 1 for names and data range of the stations
SAR sodium adsorption ratio

runoff occurs in the Tigris watershed. The watershed has six important branches at different elevations, with each branch having a water monitoring station. The principal component of the river is the Tigris (570 m a.s.l.), and its important branches are: Botan 1 (457 m a.s.l.); Bitlis stream (910 m

a.s.l.); Tigris–Cayonu stream (695 m a.s.l.); Zap water 1 (1,725 m a.s.l.); Zap water 2 (1,440 m a.s.l.); and Botan–Billori stream (465 m a.s.l.) (EIE 2002; TRSHW 2002) (Table 1).

The analyses of water quality and quantity time series data were carried out using the data

Fig. 2 Box-and-whisker plots for long-term data distribution of 13 annual water variables for 14 stations over the Euphrates river in Turkey. Sign “o” refers to outlier; the *upper and lower whisker lines* extend to the highest and lowest data values within the upper and lower limits, respectively; and the *top and bottom horizontal lines of the box* refer to the third and first quartiles (75% and 25% of the data less than or equal to this value), respectively. The *middle horizontal line of the box* refers to median value (50% of the data less than or equal to this value). *X* axis denotes 14 station numbers (see Table 1 for names and data range of the stations)



from monitoring stations of TRSHW for the Euphrates and Tigris rivers (TRSHW 2002). Fourteen and seven stations with long-term time series were used in the analyses for the Euphrates and Tigris rivers, respectively. Thirteen annual and monthly variables of water quality and quantity include flow rate (FR, $\text{m}^3 \text{s}^{-1}$), water temperature (WT, $^{\circ}\text{C}$), pH, electrical conductivity (EC, $\mu\text{mhos cm}^{-1}$), Na (meq L^{-1}), K (meq L^{-1}), Ca + Mg (meq L^{-1}), CO_3 (meq L^{-1}), HCO_3 (meq L^{-1}), Cl (meq L^{-1}), SO_4 (meq L^{-1}), sodium adsorption ratio (SAR), and boron (B, mg L^{-1}).

In the monitoring stations, a lab type EC-meter, and a glass electrode pH-meter were employed to determine EC and pH, respectively. Similarly, sodium (Na^+) and potassium (K^+) were analyzed by a flamephotometer; carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) by sulfuric acid titration; chloride (Cl^-) by silver nitrate titration (AgNO_3); calcium (Ca^{2+}) and magnesium (Mg^{2+})

by Versanat titration; sulfate (SO_4^{2-}) by subtracting the total cation amount of HCO_3^- , CO_3^{2-} , and Cl^- from the total amount of anions; boron by Carmen solution and a calorimeter (USSL 1954); and flow rate by AA price type low-level systems.

Statistical analyses were performed using Minitab 15.1. Whether or not the data follow a normal distribution was tested using Anderson–Darling test. The equality of medians was tested using the nonparametric test of Kruskal–Wallis for the 13 variables among the 14 and seven stations of the Euphrates and Tigris rivers, respectively. Where significant differences in the variables among the stations exist was determined using Kruskal–Wallis test as well as box-and-whisker plots. Mann–Kendall trend test was employed to detect linear temporal trends in the variables for the stations at $P < 0.05$ (Kendall 1970).

Fig. 2 (continued)

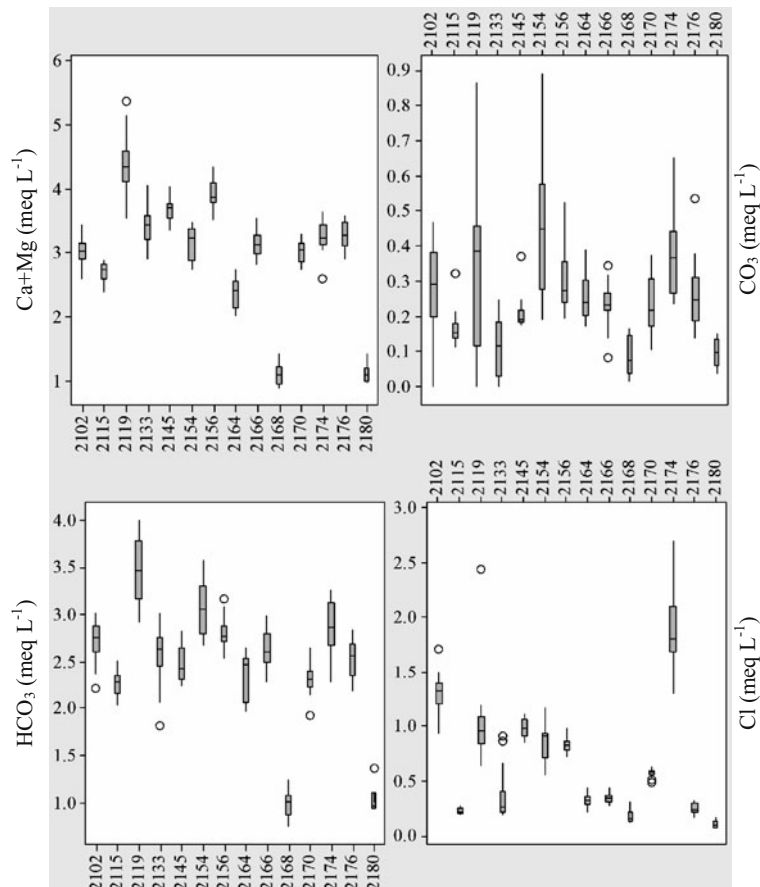
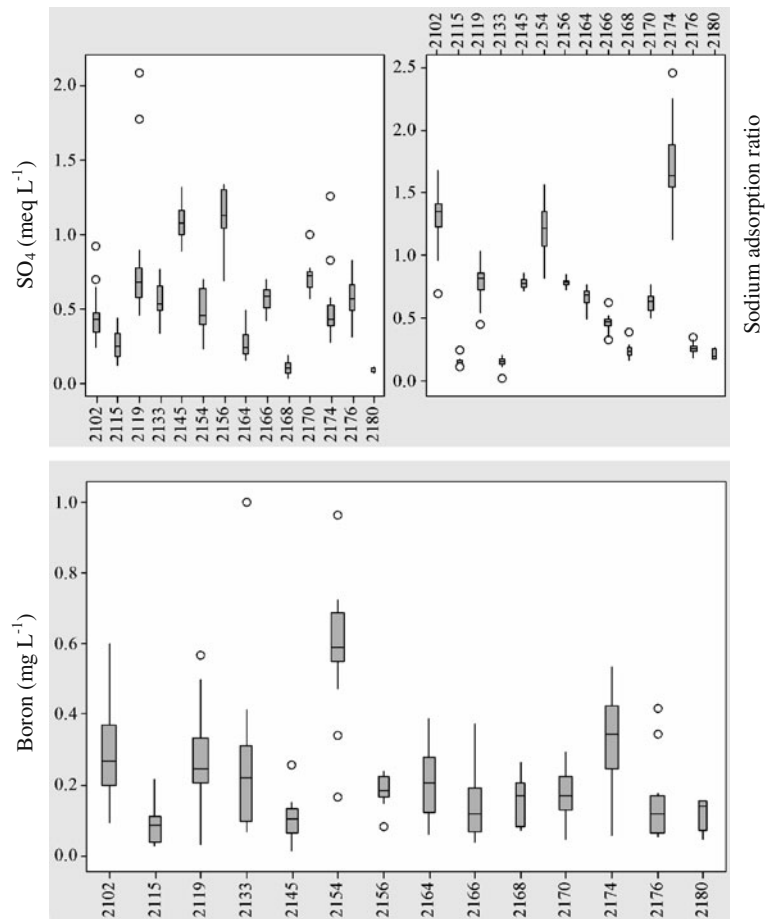


Fig. 2 (continued)**Table 5** Mann–Kendall trend results (at $P < 0.05$) for water properties from five stations of Tigris river with a monitoring period of ≥ 10 years

Station	Period (year)	FR ($\text{m}^3 \text{s}^{-1}$)	WT ($^{\circ}\text{C}$)	pH	EC ($\mu\text{mhos cm}^{-1}$)	Na (meq L^{-1})	K (meq L^{-1})
2605	22	Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing
2610	16	Decreasing	No trend	Increasing	No trend	Increasing	No trend
2617	16	No trend	No trend	Increasing	Decreasing	No trend	No trend
2626	13	No trend	No trend	No trend	No trend	No trend	Decreasing
2630	17	No trend	No trend	Increasing	Increasing	Increasing	No trend
Station	Ca+Mg (meq L^{-1})	CO_3 (meq L^{-1})	HCO_3 (meq L^{-1})	Cl (meq L^{-1})	SO_4 (meq L^{-1})	SAR	B (mg L^{-1})
2605	No trend	Increasing	No trend	No trend	Increasing	Increasing	No trend
2610	No trend	Decreasing	No trend	No trend	Increasing	Increasing	No trend
2617	Decreasing	Increasing	No trend	No trend	Decreasing	No trend	No trend
2626	No trend	No trend	No trend	No trend	Decreasing	No trend	No trend
2630	No trend	Decreasing	No trend	Increasing	No trend	Increasing	Increasing

See Table 1 for names and data range of the stations

FR flow rate; WT water temperature; EC electrical conductivity; SAR sodium adsorption ratio

Table 6 Kruskal–Wallis test results for significant differences in six water variables among seven stations over Tigris river

FR	P value	WT	P value	pH	P value	EC	P value	Na	P value	K	P value
2621 vs. 2626	0.0001	2605 vs. 2621	0.0001	2617 vs. 2630	0.0001	2605 vs. 2610	0.0001	2610 vs. 2621	0.0001	2605 vs. 2617	0.0001
2610 vs. 2626	0.0001	2617 vs. 2621	0.0001	2610 vs. 2617	0.0001	2605 vs. 2630	0.0001	2610 vs. 2626	0.0001	2617 vs. 2630	0.0001
2617 vs. 2626	0.0001	2605 vs. 2610	0.0008	2617 vs. 2633	0.0003	2610 vs. 2617	0.0001	2605 vs. 2610	0.0001	2610 vs. 2617	0.0007
2621 vs. 2633	0.0001	2621 vs. 2626	0.0064			2605 vs. 2626	0.0001	2617 vs. 2621	0.0001	2605 vs. 2633	0.0012
2605 vs. 2621	0.0001	2605 vs. 2626	0.0075			2617 vs. 2630	0.0001	2610 vs. 2630	0.0001	2630 vs. 2633	0.0014
2626 vs. 2630	0.0001	2610 vs. 2621	0.014			2610 vs. 2621	0.0003	2610 vs. 2633	0.0002	2617 vs. 2621	0.0039
2605 vs. 2626	0.0003					2617 vs. 2626	0.0005	2617 vs. 2626	0.0014		
2610 vs. 2633	0.0003					2605 vs. 2633	0.005	2605 vs. 2617	0.0035		
2621 vs. 2630	0.0004					2621 vs. 2630	0.0079	2617 vs. 2633	0.0042		
2617 vs. 2633	0.0004							2617 vs. 2630	0.0087		

See Table 1 for names and data range of the stations

FR flow rate; WT water temperature; EC electrical conductivity

Table 7 Kruskal–Wallis test results for significant differences in seven water variables among seven stations over Tigris river

Ca+Mg	P value	CO ₃	P value	HCO ₃	P value	Cl	P value	SO ₄	P value	SAR	P value	Boron	P value
2605 vs. 2610	0.0001	2610 vs. 2617	0.0001	2621 vs. 2626	0.0001	2605 vs. 2610	0.0001	2617 vs. 2630	0.0001	2610 vs. 2621	0.0001	2617 vs. 2630	0.0001
2605 vs. 2630	0.0001	2617 vs. 2630	0.0001	2626 vs. 2630	0.0001	2605 vs. 2630	0.0001	2610 vs. 2617	0.0001	2617 vs. 2621	0.0001	2605 vs. 2630	0.0001
2605 vs. 2626	0.0001	2605 vs. 2617	0.0013	2617 vs. 2621	0.0001	2610 vs. 2626	0.0001	2605 vs. 2630	0.0001	2610 vs. 2626	0.0001	2617 vs. 2621	0.0001
2610 vs. 2617	0.0001			2621 vs. 2633	0.0001	2626 vs. 2630	0.0001	2605 vs. 2610	0.0001	2610 vs. 2630	0.0001	2605 vs. 2621	0.0001
2617 vs. 2630	0.0001			2605 vs. 2626	0.0001	2610 vs. 2633	0.0001	2617 vs. 2621	0.0001	2617 vs. 2626	0.0001	2626 vs. 2630	0.0003
2617 vs. 2626	0.0001			2617 vs. 2630	0.0002	2610 vs. 2621	0.0001	2605 vs. 2621	0.0002	2617 vs. 2630	0.0002	2621 vs. 2626	0.0014
2605 vs. 2633	0.0011			2630 vs. 2633	0.0004	2630 vs. 2633	0.0002	2617 vs. 2626	0.0007	2610 vs. 2633	0.0002	2630 vs. 2633	0.0031
2605 vs. 2621	0.0033			2610 vs. 2621	0.0016	2621 vs. 2630	0.0005	2626 vs. 2630	0.0042	2617 vs. 2633	0.0006	2610 vs. 2630	0.0052
2617 vs. 2633	0.0036			2605 vs. 2617	0.0038	2610 vs. 2617	0.003	2605 vs. 2626	0.0087	2605 vs. 2610	0.001	2621 vs. 2633	0.0057
				2605 vs. 2633	0.0041	2605 vs. 2617	0.0084			2605 vs. 2617	0.0037		
				2610 vs. 2630	0.0068								

See Table 1 for names and data range of the stations

SAR sodium adsorption ratio

Fig. 3 Box-and-whisker plots for long-term data distribution of 13 annual water variables for seven stations over Tigris river in Turkey. Sign “o” refers to outlier; the *upper and lower whisker lines* extend to the highest and lowest data values within the upper and lower limits, respectively; the *top and bottom horizontal lines of the box* refer to the third and first quartiles (75% and 25% of the data less than or equal to this value), respectively. The *middle horizontal line of the box* refers to median value (50% of the data less than or equal to this value). *X* axis denotes seven station numbers (see Table 1 for names and data range of the stations)

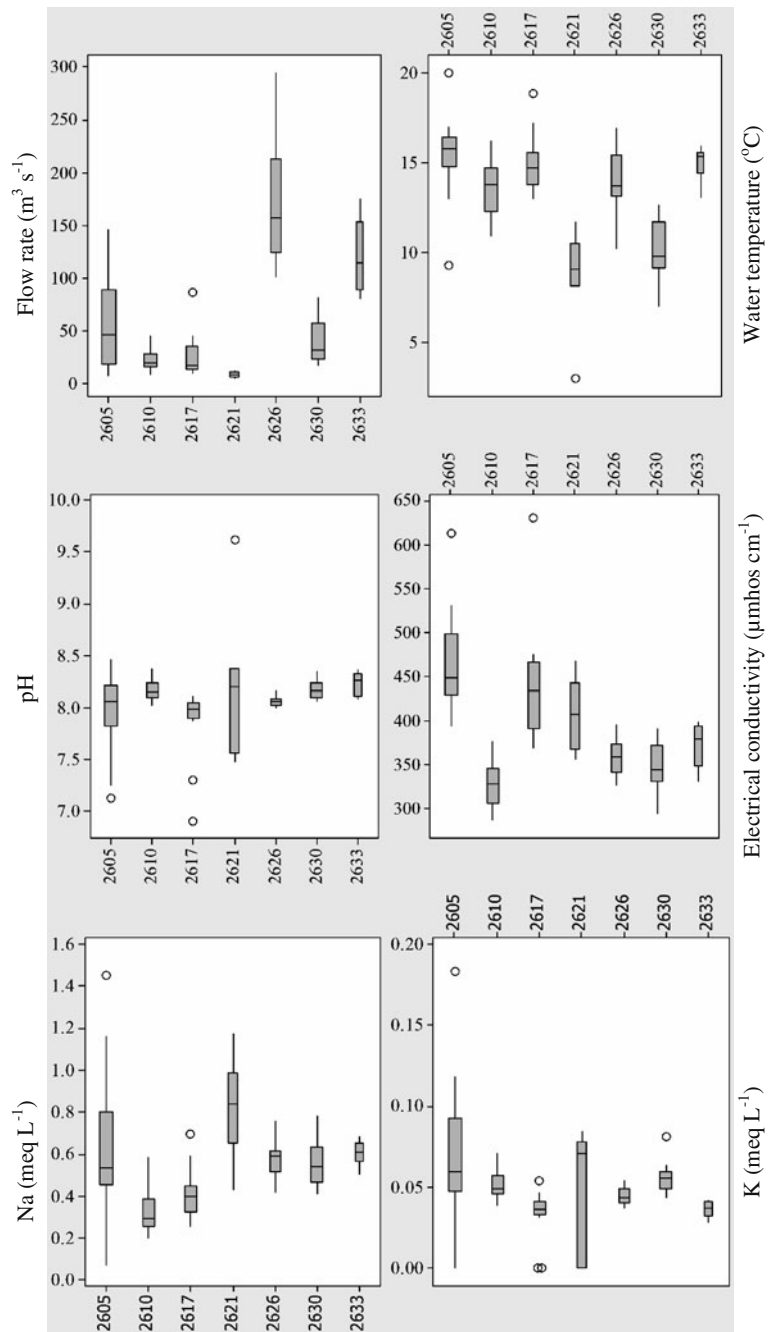


Fig. 3 (continued)

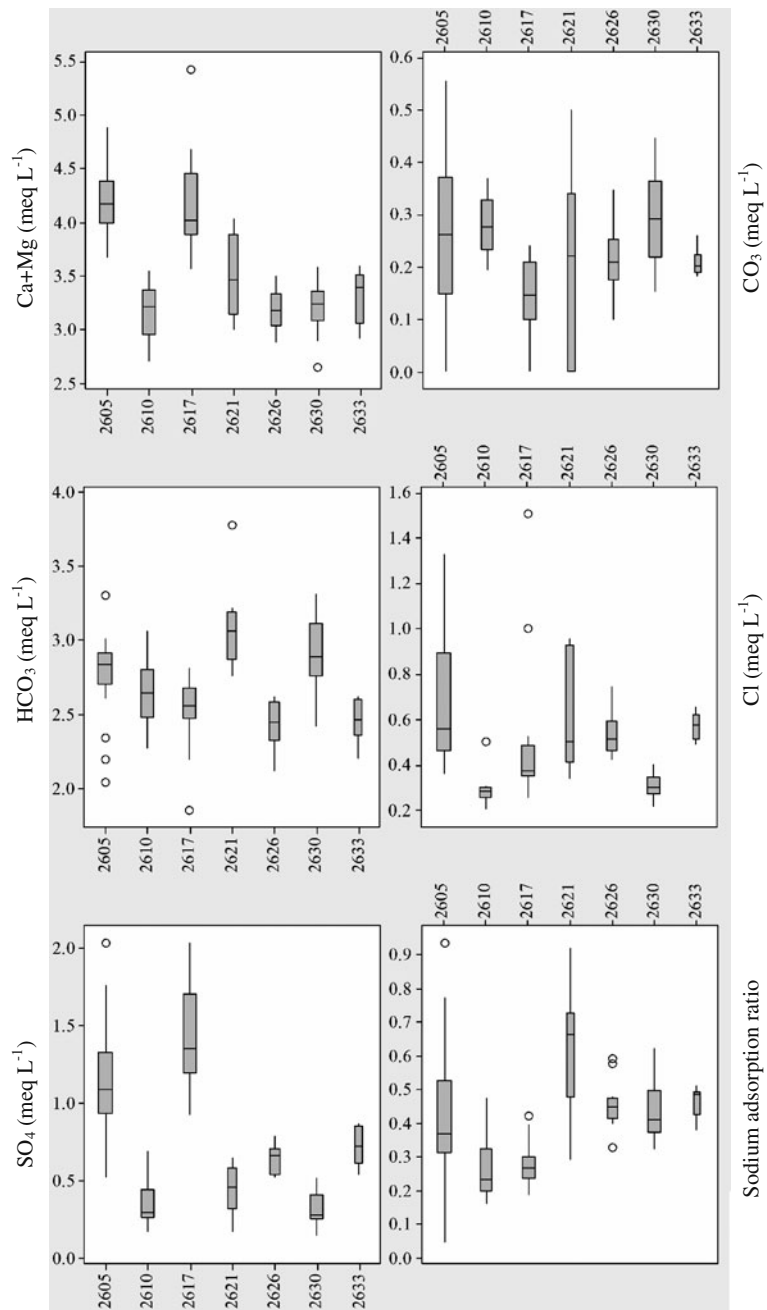
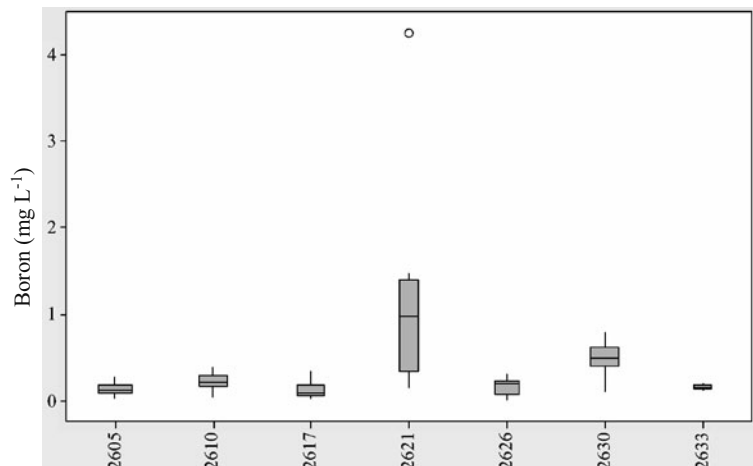


Fig. 3 (continued)

Results and discussion

For the Euphrates river, mean ($\pm$ standard deviation) values during the period of 1971 to 2002 were estimated at $111.5 \text{ m}^3 \text{ s}^{-1}$ (157.4) for FR; 11.2°C (2.7) for WT; 8.1 (0.19) for pH; $387.5 \mu\text{mhos cm}^{-1}$ (116.8) for EC; 0.93 meq L^{-1} (0.65) for Na; 0.06 meq L^{-1} (0.04) for K; 3.13 meq L^{-1} (0.81) for $\text{Ca}^{2+} + \text{Mg}^{2+}$; 0.26 meq L^{-1} (0.15) for CO_3 ; 2.58 meq L^{-1} (0.61) for HCO_3 ; 0.72 meq L^{-1} (0.53) for Cl; 0.56 meq L^{-1} (0.31) for SO_4 ; 0.72 meq L^{-1} (0.48) for SAR; and 0.23 mg L^{-1} (0.17) for B. The maximum and minimum FRs were found to be for Euphrates 3 ($606 \text{ m}^3 \text{ s}^{-1}$) and Dumlu 1 ($0.8 \text{ m}^3 \text{ s}^{-1}$), respectively. Mean minimum and maximum WTs were 2.0°C for Dumlu 1 and 17.6°C for Murat 1. Along the gradient from north to south, WTs decreased due to the increased elevations of the water monitoring stations. The lowest water temperature belonged to Dumlu 2 whose elevation is highest (2,000 m a.s.l.). The highest water temperature (15.3°C) belonged to Goksu monitoring station (397 m a.s.l.). Mean pH was lowest (7.8) for Karasu and highest (8.2) for Dumlu 1. Water pH near urban areas was found to be relatively high. EC was lowest ($98.8 \mu\text{mhos cm}^{-1}$) for Dumlu and highest ($722.2 \mu\text{mhos cm}^{-1}$) for Euphrates 1. Notably low Na and Ca + Mg concentrations in the Euphrates watershed yielded a low SAR in the watershed, with the lowest (0.14) and highest (1.71) SAR values for Munzur stream and Murat 2 stations, respectively. Na ranged from 0.16 to 2.26 meq L^{-1} .

Boron, an indicator for heavy metal pollution, was not found to be problematic, with the lowest (0.09 mg L^{-1}) and highest (0.58 mg L^{-1}) concentrations for Goksu and Karasu stations, respectively.

Mann–Kendall trend test revealed linear temporal variations over 10 years in the 13 variables for the 13 monitoring stations of the Euphrates river (Table 2). Particularly, pH significantly increased for the majority of the water monitoring stations ($P < 0.05$) except for the Dumlu 1 and Euphrates 3 stations ($P > 0.05$). Only Murat 2 and Tacik stations showed a significant increasing trend in EC, whereas Peri stream showed a linear trend of decreasing EC (Table 2). The most significant changes in terms of Na and K concentrations occurred in the form of linear increases for the Euphrates 1 and Murat 2 monitoring stations. Ca + Mg significantly increased only at the Tacik station. SAR significantly increased linearly for the Murat 1, Goksu, Euphrates 1, and Munzur stations. Linear increase in boron was significant at Euphrates 2 only.

Significant multiple comparisons of the 14 stations over the Euphrates river for medians of the 13 variables based on the Kruskal–Wallis test are presented in Tables 3 and 4. The magnitude and direction of differences among the stations of the Euphrates river are given in Fig. 2. The upper Euphrates river (Dumlu 1) significantly had lower values of FR, WT, EC, Cl, and SO_4 than did the

lower Euphrates river (Euphrates 3). The middle Euphrates river (Murat 2) had significantly higher Na, K, HCO_3 , Cl, SAR, and B and lower EC and SO_4 than the lower Euphrates river (Euphrates 3).

For the Tigris river, mean ($\pm$ standard deviation) values for the period of 1973 to 2002 are $58.00 \text{ m}^3 \text{ s}^{-1}$ (59.75) for FR; 13.3°C (2.8) for WT; 8.0 (0.3) for pH; $392.9 \text{ } \mu\text{mhos cm}^{-1}$ (65.5) for EC; 0.54 meq L^{-1} (0.23) for Na; 0.05 meq L^{-1} (0.26) for K; 3.61 meq L^{-1} (0.55) for Ca+Mg; 0.23 meq L^{-1} (0.12) for CO_3 ; 2.69 meq L^{-1} (0.30) for HCO_3 ; 0.49 meq L^{-1} (0.25) for Cl; 0.77 meq L^{-1} (0.49) for SO_4 ; 0.39 meq L^{-1} (0.16) for SAR; and 0.29 mg L^{-1} (0.47) for B. The lowest and highest FRs belonged to Zap stream 1 and Botan stations, respectively. The lowest and highest WTs were 3°C for Zap stream 1 and 20°C for Tigris. EC varied between 287 and $630 \text{ } \mu\text{mhos cm}^{-1}$. SAR was found to be significantly low in the Tigris watershed.

Mann–Kendall trend test revealed linear temporal variations over 10 years in the 13 variables for the six monitoring stations of Tigris river (Table 5). A significant linear trend of decrease occurred in FR for the Tigris 1 and 2 stations, while a significant linear trend of increase occurred in WT at Tigris 1; in pH at all the stations except for Botan; in both SAR and Na at the Tigris 1 and 2 and Zap water 2 stations; and in B at Zap water 2 (Table 5). HCO_3 showed no temporal trend for the stations of the Tigris river.

Significant multiple comparisons of the seven stations over the Tigris river for medians of the 13 variables based on the Kruskal–Wallis test are presented in Tables 6 and 7. The magnitude and direction of differences among the stations of the Tigris river are given in Fig. 3. The upper west Tigris river (Bitlis creek) had higher EC, Ca + Mg, and SO_4 and lower FR, Na, and SAR than the lower Tigris river (Botan 1). The upper east Tigris river (Zap water 1) had higher HCO_3 and B and lower FR and WT than the lower Tigris river.

Conclusion

Monitoring quality and quantity of water resources is of greater importance when sustainable management of transboundary watersheds is con-

cerned. In this regard, the Euphrates and Tigris rivers form one of the most important watersheds in the Middle East. Having a total surface flow of 186 billion cubic meters per year, the Euphrates and Tigris watersheds occupy a quarter of the entire Turkish surface flow, with the Euphrates river providing 16 billion cubic meters per year of water to such downstream countries as Syria and Iraq. The present rate of water withdrawal from these semi-arid watersheds is most likely to increasingly continue in order to be able to meet water demands given the interacting influence of a total of 1.6 million hectares of irrigated agricultural land proposed by the GAP project and changing global climate and land-use/cover. The inadequacy of wastewater treatment plants in the watersheds poses an additional threat to the ecosystem health of the Euphrates and Tigris watersheds considering that some streams are discharged up to $2,000 \text{ m}^3 \text{ s}^{-1}$ of wastewater (World Resources Institute 1990).

Relative to the lower Euphrates river, the upper Euphrates river had low FR, WT, EC, Cl, and SO_4 , while the middle Euphrates river had high Na, K, HCO_3 , Cl, SAR, and B. Relative to the lower Tigris river, the upper west Tigris river had high EC, Ca + Mg, and SO_4 and low FR, Na, and SAR, while the upper east Tigris river had high HCO_3 and B and low FR and WT. The patterns of water quality and quantity among the upper, middle, and lower watersheds quantified in this study are most likely to be coupled to the land-cover/use and management dynamics. Changes in quantity and quality of water resources in Turkey, therefore, need to be continuously monitored and detected on the watershed scale using a greater number of stations coupled with multivariate analyses of remotely sensed and site-specific data.

Currently, water quality of the Euphrates and Tigris rivers for agricultural irrigation is not posing salinity hazard for crop productivity and soil fertility. However, with the start of irrigation in the GAP region, these semiarid watersheds may suffer from soil salinity and alkalinity, with excessive use of irrigation and high evapotranspiration rate. It is, therefore, urgent that adaptive management practices such as drip irrigation, reduced-till, conservative residue management should be adopted throughout the watersheds in order to

secure long-term ecosystem productivity and sustainable agricultural communities.

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