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# Water quality of the Değirmendere stream, drinking water source of Trabzon Province, Turkey

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**ABSTRACT**

Trabzon Province with a total population of 757,898 is the biggest city on the Southeastern Black Sea Coast. Domestic water demand of the city is supplied by the Değirmendere and Galyan streams after treatment at the drinking water treatment plants of the Trabzon Metropolitan Municipality. The main purpose of this study is to monitor and assess drinking water quality of these surface water resources before treatment with reference to 30 water-quality indicators. The monitoring results covering 1-year period revealed that each stream had high-quality water except for total Kjeldahl nitrogen, orthophosphate phosphorus, and total iron, by which each stream was classified as slightly polluted according to the Turkish Surface Water Quality Regulation. The results for the untreated stream waters were well below the permissible levels mandated or proposed by national and international references except for total iron. However, the post-treatment quality and safety of the stream waters used for drinking purposes matched the standards as indicated in the drinking water-quality reports of the Trabzon Metropolitan Municipality.

*Keywords:* Değirmendere stream; Drinking water quality; Trabzon Province; Treatment plants

## 1. Introduction

Safe and good water quality is essential for sustaining basic human functions, health and food production, as well as preserving the integrity of the world's ecosystems. It provides essential elements, and supports the digestion of food, adsorption, transportation and use of nutrients and the elimination of toxins and wastes from the body. However, when polluted, it may become the source of undesirable substances dangerous to human health [1,2].

Numerous water-quality studies have been recently conducted in different rivers around the world, such as Sinos, Brazil [3]; Selenga, Russia [4]; Nestos, Greece [5]; Araks, Armenia [6]; Double Mountain Fork Brazos, USA [7]; Lis, Portugal [8]; Kosi, India [9]; Semenyih, Malaysia [10]; Enborne, United Kingdom [11]; Wisznia, Poland [12]; Danube, Serbia [13]; and Shanchong, China [14]. Similarly, many water-quality studies have also been reported from different rivers or streams of Turkey, such as Saricay [15], Ceyhan [16], Perisuyu [17], Gediz [18], Koprucay [19], Karasu [20], Kizilirmak [21], Kirmir [22], Melen [23], Seydisuyu [24], Bulakbasi [25], and Riva [26].

With a mean surface water potential of 560 × $10^6$ $m^3$ [27], the Değirmendere Stream watershed is of prime importance since domestic water demand of Trabzon people is supplied by this watershed. Altun et al. [28] monitored the surface water quality in a limited number of indicators. Uguz et al. [29] paid attention to alkylphenolic compounds and did not detect. Gultekin et al. [30] monitored the surface water quality in a limited duration, only spring. Considering the previous studies [28–30] in the Değirmendere Stream, the present study covers both more water-quality indicators and four seasons. The main purpose of this study is to classify the Değirmendere and Galyan streams supplying domestic water to Trabzon Province, northeast Turkey, with reference to the Turkish Surface Water Quality Regulation [31]. Another aim of the current study is to assess the quality and safety of the water used for drinking purposes according to the national regulation [32] and standard [33], and international directive and guidelines [34–36] by monitoring temporal variations of 30 water-quality indicators for a period from March 2010 to February 2011.

Domestic water demand of Trabzon people was supplied by the Değirmendere stream-valley alluvial aquifer until 1992. Twenty-seven water wells with a depth of 30–39 m were drilled by the General Directorate of State Hydraulic Works at the most productive part of this aquifer (Fig. 1). However, although this valley was suitable for tapping groundwater, it was opened for settlement for various reasons; consequently, groundwater quality in the aquifer was degraded.

As of May 1992, water demand of the city was supplied with the water taken from the Değirmendere Stream (Fig. 2) by means of a regulator, namely Esiroğlu, and a conveyance line with a length of 675 m after the treatment at the drinking water treatment plants of the Trabzon Metropolitan Municipality. Its construction was started in the year 1987, and it was completed in 1992, due to the degradation in groundwater's quality, the serious decline in the water well yield, and the dramatic increase in the city population [37].

The surface water quality of the Değirmendere Stream, passing through the city center of Maçka, receiving untreated domestic wastewater, and draining into the Southeastern Black Sea, was ironically degraded as time passed. As a result of over pollution of the Değirmendere Stream, the water of the Galyan Stream, which is tributary of the Değirmendere Stream, came into use (Fig. 3) to supply freshwater for the city by means of a regulator, namely Galyan, and a conveyance line with a length of 2,700 m after being treated at the drinking water treatment plants. This water resource has been used since 2001 [37–39].

However, surface water of the Galyan Stream was not sufficient due to increasing water demand and decreasing discharge of the stream during the summer months. Therefore, the water of the Değirmendere Stream had to be used after treatment. Yet, the drinking water treatment plants could not meet the requirements both economically and technically [38,39].

Because of the above-mentioned reasons, the need for a dam, Atasu Dam, on the main branch of the Galyan Stream has arisen. Construction of the Atasu Dam, located 17 km southwest of Trabzon Province, was started by the General Directorate of State Hydraulic Works on April 27, 1998 and completed on December 28, 2010.

## 2. The study area

With a coastline of 135 km, Trabzon Province is located in the Turkish coast of Southeastern Black Sea. The province with a surface area of 4,685 km$^2$ is situated on the slope of the hills. Neighboring provinces are Gümüşhane to the southwest, Bayburt to the southeast, Giresun to the west, and Rize to the east. Trabzon has a typically moderate climate that is neither too warm in summers and nor too cold in winters [38,40]. Considering the meteorological records covering a long period between 1950 and 2015 from Trabzon Meteorological Station, the average minimum monthly temperature changes between 4.4°C in February and 20.6°C in August, while the average maximum monthly temperature changes between 10.9°C in January and 26.8°C in August. Trabzon receives an average annual precipitation of 810.2 mm ranging from 34.4 mm in July to 116.4 mm in October [41]. Average annual precipitations in neighboring provinces are 438.3 mm in Bayburt [42], 461.3 mm in Gümüşhane [43], 1,266.0 mm in Giresun [44], and 2,245.3 mm in Rize [45], respectively.

The total population of Trabzon is 757,898, and 56.3% of population live in city centers according to the 2012 census [46]. Sanitary sewage systems serve 454,306 people

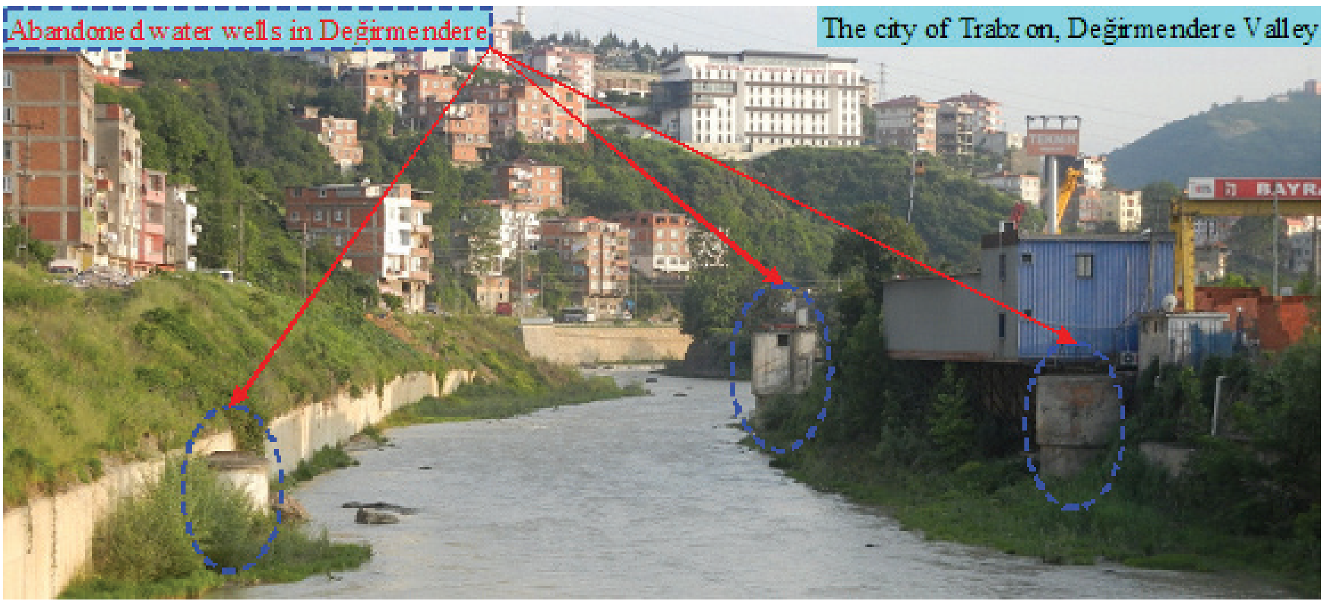


Fig. 1. View from several water wells disused for a long time in the Değirmendere Stream (Trabzon Province, Turkey) by the author on May 12, 2014.

Fig. 2. Views from the regulator on the Değirmendere Stream (Trabzon Province, Turkey) by the author on November 3, 2010.

Fig. 3. Views from the regulator on the Galyan Stream (Trabzon Province, Turkey) by the author on November 3, 2010.

according to the Municipal Wastewater Statistics Survey in 2012 [47]. About 23.474 × $10^6$ $m^3$ per year of wastewater are generated, 20.472 × $10^6$ $m^3$ of which are discharged by deep sea discharge systems to the Black Sea, and 2.912 × $10^6$ $m^3$ of which is discharged through the streams to the Black Sea [47]. As a result of all this discharge, coastal eutrophication occurs.

The Değirmendere Stream originates from Kalkanlı and Zigana Mountains having an elevation of 3,080 m and is formed by small streams, namely Hamsiköy, Maçka, Larhan, Sumela, Galyan, Kuştul, and Ziganoy. After it is formed, it passes through the settlements of Hamsiköy, Maçka, Esiroğlu, Çağlayan, and Değirmendere before draining into the Southeastern Black Sea at the junction 41°00′09.3″ N–39°45′25.1″ E (Fig. 4).

The Galyan Stream watershed, sub-basin of the Değirmendere Stream, lies between longitudes 39°39′ and 39°45′ and latitudes 40°45′ and 40°52′, and surrounds the Galyan Stream, the main branch, and the Kuştul Stream, the tributary. The Galyan Stream with a 25.5-km-long main branch joins the Değirmendere Stream with a 55-km-long main branch at the junction 40°52′54.2″ N–39°41′58.2″ E (Fig. 4).

The Esiroğlu regulator, 40°52′33.5″ N–39°41′19.1″ E with an elevation of 152 m, on the Değirmendere Stream (Fig. 2) and the Galyan regulator, 40°51′51.6″ N – 39°41′52.5″ E with an elevation of 178 m, on the Galyan Stream (Fig. 3) were selected as water monitoring and sampling stations. The study was started in March 2010, conducted monthly, and terminated in February 2011. To put it differently, 12 studies were periodically conducted over a year.

## 3. Materials and methods

### *3.1. Drinking water treatment*

The drinking water treatment plant (Fig. 5) located on a land of 100,000 $m^2$ has a conventional treatment with a capacity of 165,000 $m^3$ per day. Conventional treatment consists of the following unit processes: coagulation, flocculation, clarification and filtration, and is typically followed by disinfection at full-scale. The coagulant, such as aluminum sulfate or polyaluminum chloride, is added to the raw water, and it is rapidly mixed so that the coagulant is circulated throughout

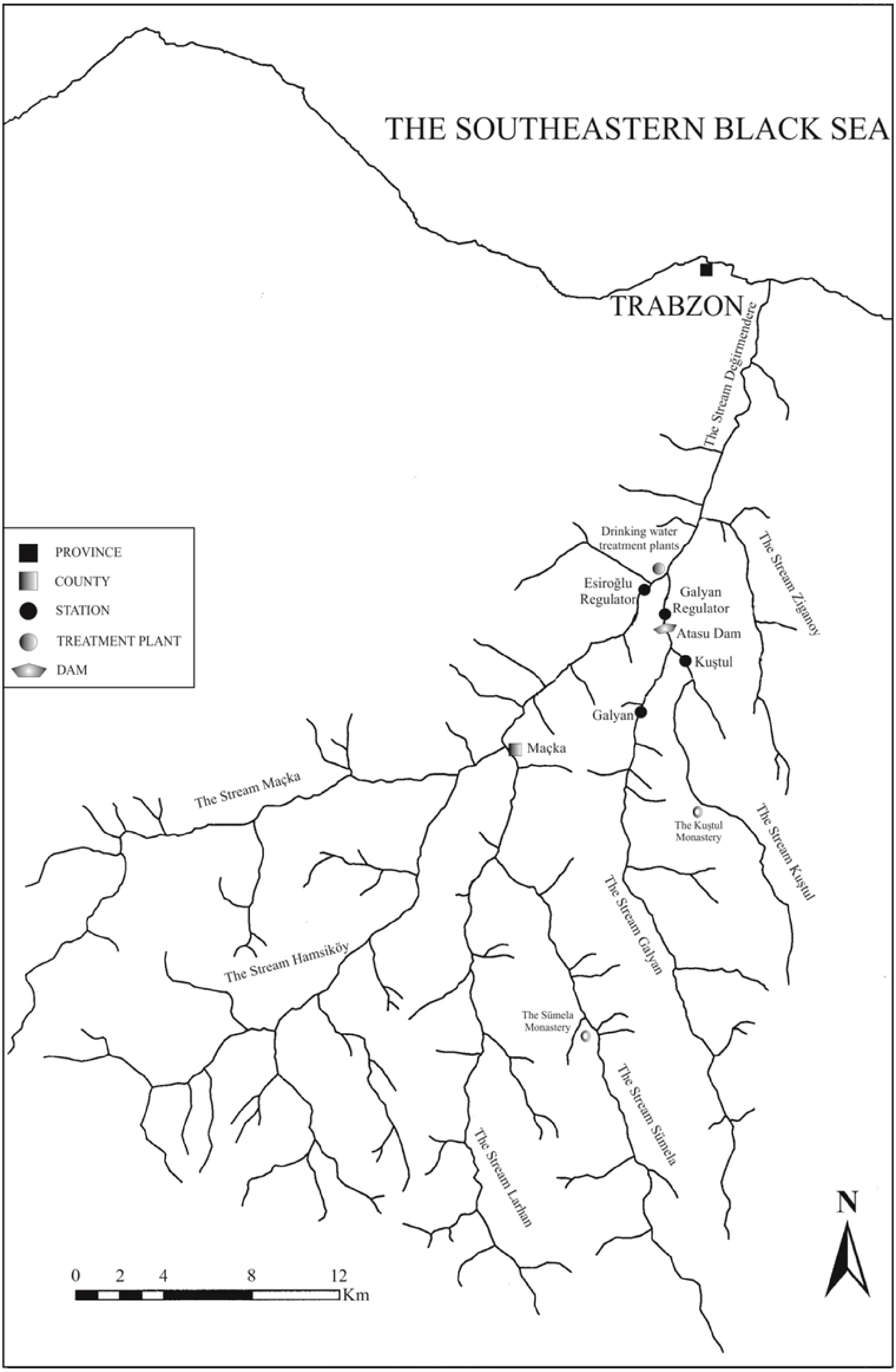


Fig. 4. The Değirmendere Stream watershed, Southeastern Black Sea, and water monitoring and sampling stations.


Fig. 5. View from the drinking water treatment plant in the Değirmendere Valley (Trabzon, Turkey) by the author on September 30, 2014.

the water. Rapid mixing is achieved in the first mixer (M1) having one weir and four baffles. The flocculant, such as polyelectrolyte, is then added. Flocculation is achieved in the second mixer (M2) by gentle mixing so as to maximize the number of collisions between suspended particles and flocs, without breaking the flocs up through rapid mixing. The treatment plant has four rectangular clarifiers, each of which has a base width of 432 $m^2$ and a volume of 1,950 $m^3$. There are seven rectangular sand filter beds, each of which has a base width of 134 $m^2$ and a volume of 750 $m^3$. Each gravity rapid sand filter has a filter media of 1,050 mm (Table 1). There is also a clean water tank of 12,000 $m^3$ in the plant.

Table 1
The gravity rapid sand filter

| Type | Size, mm | Depth, mm |
|---|---|---|
| Fine sand | 0.60–1.18 | 700 |
| Coarse sand | 1.18–2.36 | 100 |
| Gravel | 2.36–4.75 | 100 |
| Gravel | 6.70–13.2 | 150 |

### 3.2. The stream gauging

Three stream gauging stations are operated by the General Directorate of State Hydraulic Works. The Öğütlü is on the Değirmendere Stream; the Bibat is on the Galyan Stream; and the Meyvecik is on the Kuştul Stream. The first one is close to the Esiroğlu regulator while the latter two are close to the Galyan regulator. Therefore, it is thought that the flow rate from the Öğütlü gauging station may be used for the Esiroğlu regulator, and the total flow rate from the Bibat and Meyvecik gauging stations may be used for the Galyan regulator. The characteristics of stream gauging stations are given in Table 2.

### 3.3. The surface water monitoring

The surface water temperature ($t$, °C), pH, dissolved oxygen concentration (DO, mg $L^{-1}$), electrical conductivity (EC, μS $cm^{-1}$) and turbidity ($T$, NTU) were measured *in situ* using a portable field meter, Horiba U-10. The field meter uses the glass electrode method for pH measurement, the membrane electrode method for DO measurement, the four-electrode method for EC measurement and the light-absorption-scattering method for $T$ measurement. The measurements except for $T$ were simultaneously verified by HQ40D, another portable field meter, which also measures total dissolved solids (TDS, mg $L^{-1}$) and salinity (Sal, ‰).

### 3.4. The surface water sampling and total suspended solids determination

Sampling, preservation, and transport of the water samples to the laboratory were done in alignment with the guidelines of the Standard Methods for the Examination of Water and Wastewater [48]. Plastic sample bottles, pre-cleaned with 1 M $HNO_3$ and rinsed with double-distilled water, were used to collect the water samples.

The surface water samples were filtered through a glass microfiber filter with a pore size of 1.2 μm under negative pressure in order to separate the water from the suspended solids. Once the water was clarified, the material collected was oven-dried at 105°C until the sample reached a constant weight and total suspended solids (TSS) was determined in terms of mg $L^{-1}$.

### 3.5. The spectrophotometric analysis

The surface water samples were filtered for the second time through a cellulose acetate membrane filter with a pore size of 0.45 μm under negative pressure at the Analytical Chemistry Graduate Laboratory, located in Karadeniz Technical University in Trabzon Province.

Table 2
Location features of the gauging stations in the Kuştul, Galyan, and Değirmendere streams

| Flow monitoring station name | Stream | Coordinates | Drainage area (km$^2$) | Operating altitude (m) |
|---|---|---|---|---|
| Meyvecik | Kuştul | 40°50′28.2 N–39°42′42.8″ E | 55.4 | 322 |
| Bibat | Galyan | 40°49′40.7 N–39°41′06.2″ E | 120.2 | 372 |
| Ögütlü | Değirmendere | 40°51′50.5 N–39°40′57.9″ E | 728.4 | 160 |

Calcium ion ($Ca^{2+}$), magnesium ion ($Mg^{2+}$), water hardness (WH), fluoride ion ($F^-$), chloride ion ($Cl^-$), sulfate ion ($SO_4^{2-}$), ammonium nitrogen ($NH_4^+$–N), nitrite nitrogen ($NO_2^-$–N), nitrate nitrogen ($NO_3^-$–N), total nitrogen (TN), orthophosphate phosphorus ($o$-$PO_4^{3-}$–P), anionic surfactants as methylene blue active substances (MBAS), total carbon (TC) together with total inorganic carbon (TIC) and total organic carbon (TOC), chemical oxygen demand (COD), aluminum ion ($Al^{3+}$), copper ion ($Cu^{2+}$), manganese ion ($Mn^{2+}$), total chromium (Cr) and total iron (Fe) were measured in the laboratory using a UV-vis spectrophotometer (Cadas 200) according to the Standard Methods [48]. Total Kjeldahl nitrogen (TKN) was calculated employing TN–($NO_2^-$–N+$NO_3^-$–N). The analyses were conducted three times for each sample in a temperature-controlled room (21°C ± 2°C). The final result was presented as the arithmetic mean of the triplicate analyses.

### 3.6. The surface water-quality assessment

The qualitative classification for the surface waters from the Değirmendere and Galyan streams was conducted with respect to the Turkish Surface Water Quality Regulation (TSWQR) [31]. It divides inland waters into four classes: Class I stands for high-quality water, Class II for slightly polluted water, Class III for polluted water, and Class IV for highly polluted water (Table 3).

The quality and safety of the untreated stream waters were assessed for drinking purposes based on the national regulation (Regulation Concerning Water Intended for Human Consumption [RCWIHC]) [32] and standard (Turkish Standard 266-Water Intended for Human Consumption) [33]. In TS 266, the waters are divided into two classes and two types: Class I refers to spring waters and Class II refers to water intended for human consumption apart from spring waters. Type I refers to treated spring water while Type II refers to drinking water and water for other uses. Based on the classification by TS 266, the surface waters from the Değirmendere and Galyan streams are regarded as Class II and Type II.

The quality and safety of the untreated stream waters were secondly assessed for drinking purposes based on the international directive (the Council Directive 98/83/EC) and guidelines (World Health Organization and United States Environmental Protection Agency). The drinking water upper threshold values for the monitored water-quality indicators are given in Table 3.

### 3.7. The statistical analysis

Two statistical features, namely the average and standard deviation, were calculated for both stations. The water quality data were analyzed with the IBM SPSS Statistics 23 for Windows. The Pearson correlation analysis was used to determine whether there were relationship between any two indicators.

## 4. Results and discussion

The basic statistics of the water-quality indicators monitored for the surface waters from the regulators, namely Esiroğlu and Galyan, are given in Table 3. The Pearson correlation coefficients shown in a half matrix (Table 4) are the results of statistical analyses for possible relationships between water-quality indicators monitored.

### 4.1. Flow rate

The flow data from the Bibat and Meyvecik gauging stations were not reliable due to various construction activities in the Galyan Stream watershed such as bridges, levees, sewerage systems, soil-saving dams and relocation of roads, and thus could not be employed. However, reliable flow data for the Esiroğlu regulator could only be obtained from the Öğütlü gauging station on the Değirmendere Stream watershed.

Considering the daily mean values for the days when water monitoring and sampling were conducted, the flow rates in the Değirmendere Stream fluctuated throughout the period of study. The lowest flow rate was 1.88 m$^3$ s$^{-1}$, gauged in winter, and the highest flow rate was 34.60 m$^3$ s$^{-1}$, gauged in spring. The annual mean flow rate was calculated as 9.05 m$^3$ s$^{-1}$. On a seasonal basis, the order of decreasing flow rates in the Değirmendere Stream is: Spring > Summer > Autumn > Winter.

### 4.2. Water temperature

The winter presented the coldest temperatures: 8.5°C and 10.1°C, while the summer was the warmest season, with temperatures of 19.3°C and 19.2°C in the Değirmendere and Galyan streams, respectively. The annual mean temperatures were calculated as 13.2°C and 13.4°C, respectively. The water of the each stream was classified as high quality, based on water temperature, according to the TSWQR [31]. Similarly, Bulut et al. [38] classified the Galyan Stream as high quality, based on an annual mean water temperature of 11.2°C.

### 4.3. pH

The pH values were lower during spring, 8.04 for Değirmendere and 7.78 for Galyan, and showed a steadily increasing trend throughout the study period. The higher pH values were during winter, 8.52 for the former and 8.20 for the latter. The annual mean pH values were calculated as 7.98 and 8.23, respectively, showing a minor difference between the two stations. The both streams were classified as high quality [31] in terms of pH, and the values throughout the study period fell within the pH range recommended by RCWIHC [32] and TS 266 [33], which complies

Table 3
Basic statistics of the water-quality indicators monitored for the Esiroğlu and Galyan regulators (the Değirmendere Stream watershed, the Eastern Black Sea Basin, northeast Turkey), and the water-quality limit values for these indicators with reference to the national and international directive and guidelines

| Water-quality indicators | | Galyan regulator, the Galyan Stream | | | | Esiroğlu regulator, the Değirmendere Stream | | | | TSWQR (2015) | | | | TS 266 (2005) | | RCWIHC (2005) | EU (1998) | WHO (2004) | US EPA (2009) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Mean | SD | Min | Max | Mean | SD | Class I | Class II | Class III | Class IV | Class I–II Type I | Class II Type II | | | | |
| Q | ($m^3 s^{-1}$) | – | – | – | – | 1.88 | 20.70 | 9.05 | 6.52 | – | – | – | – | – | – | – | – | – | – |
| t | (°C) | 8.5 | 19.1 | 13.4 | 4.2 | 8.0 | 20.0 | 13.2 | 4.7 | ≤25 | ≤25 | ≤30 | >30 | – | – | – | – | – | – |
| DO | ($mg L^{-1}$) | 8.85 | 11.10 | 9.97 | 0.83 | 8.83 | 11.26 | 10.33 | 0.88 | >8 | 6 | 3 | <3 | – | – | – | – | – | – |
| pH | | 7.70 | 8.26 | 7.98 | 0.17 | 8.01 | 8.53 | 8.23 | 0.20 | 6.5–8.5 | 6.5–8.5 | 6.0–9.0 | <6.0–>9.0 | 6.5–9.5 | 6.5–9.5 | 6.5–9.5 | 6.5–9.5 | 6.5–9.5 | 6.5–8.5 |
| EC | ($\mu S cm^{-1}$) | 99.2 | 508 | 202 | 126.1 | 123.3 | 343 | 218 | 90.6 | <400 | 1,000 | 3,000 | >3,000 | 650 | 2,500 | 2,500 | 2,500 | – | – |
| TDS | ($mg L^{-1}$) | 46.8 | 246.0 | 96.5 | 61.4 | 58.3 | 164.7 | 104.0 | 43.9 | – | – | – | – | – | – | – | – | – | 500 |
| Salinity | (‰) | 0.05 | 0.25 | 0.10 | 0.06 | 0.06 | 0.16 | 0.10 | 0.04 | – | – | – | – | – | – | – | – | – | – |
| T | (NTU) | 0 | 450 | 158 | 147 | 0 | 140 | 72 | 46 | – | – | – | – | 5 | 5 | N.A.C. | N.A.C. | – | 5 |
| TSS | ($mg L^{-1}$) | 13.8 | 344.8 | 86.5 | 111.5 | 9.2 | 62.7 | 38.3 | 21.7 | – | – | – | – | – | – | – | – | – | – |
| $Ca^{2+}$ | ($mg L^{-1}$) | 23.8 | 53.5 | 34.4 | 12.2 | 28.6 | 62.7 | 41.7 | 14.2 | – | – | – | – | – | – | – | – | – | – |
| $Mg^{2+}$ | ($mg L^{-1}$) | N.D. | 3.14 | N.C. | N.C. | N.D. | 4.46 | N.C. | N.C. | – | – | – | – | – | – | – | – | – | – |
| WH | (°dH) | 3.34 | 8.23 | 4.96 | 1.93 | 4.01 | 9.82 | 6.17 | 2.45 | – | – | – | – | – | – | – | – | – | – |
| $CaCO_3$ | ($mg L^{-1}$) | 60 | 147 | 89 | 34 | 72 | 176 | 110 | 44 | – | – | – | – | – | – | – | – | – | – |
| $F^-$ | ($mg L^{-1}$) | 0.115 | 0.435 | 0.203 | 0.091 | 0.088 | 0.280 | 0.180 | 0.071 | ≤1 | 1.5 | 2 | >2 | 1 | 1.5 | 1.5 | 1.5 | 1.5 | 2.0 |
| $Cl^-$ | ($mg L^{-1}$) | 0.000 | 7.880 | 3.265 | 2.098 | 0.748 | 5.500 | 3.518 | 1.378 | – | – | – | – | 30 | 250 | 250 | 250 | 250 | 250 |
| $SO_4^{2-}$ | ($mg L^{-1}$) | <40.0 | 50.1 | <40.0 | N.C. | <40.0 | <40.0 | <40.0 | N.C. | – | – | – | – | 25 | 250 | 250 | 250 | 250 | 250 |
| $NH_4^+$ | ($mg L^{-1}$) | – | – | – | – | – | – | – | – | – | – | – | – | 0.050 | 0.500 | 0.500 | 0.500 | – | – |
| $NH_4^+$–N | ($mg L^{-1}$) | 0.065 | 0.182 | 0.106 | 0.048 | 0.034 | 0.142 | 0.086 | 0.030 | <0.2 | 1 | 2 | >2 | – | – | – | – | – | – |
| $NO_2^-$ | ($mg L^{-1}$) | – | – | – | – | – | – | – | – | – | – | – | – | 0.100 | 0.500 | 0.500 | 0.500 | 3 | – |
| $NO_2^-$–N | ($mg L^{-1}$) | N.D. | 0.002 | N.C. | N.C. | N.D. | 0.021 | 0.005 | 0.007 | <0.010 | 0.060 | 0.120 | >0.300 | – | – | – | – | – | 1 |
| $NO_3^-$ | ($mg L^{-1}$) | – | – | – | – | – | – | – | – | – | – | – | – | 25 | 50 | 50 | 50 | 50 | – |
| $NO_3^-$–N | ($mg L^{-1}$) | 0.515 | 2.060 | 1.190 | 0.497 | 0.211 | 1.460 | 0.817 | 0.341 | <5 | 10 | 20 | >20 | – | – | – | – | – | 10 |
| TKN | ($mg L^{-1}$) | 0.260 | 1.055 | 0.597 | 0.270 | 0.203 | 1.006 | 0.512 | 0.280 | <0.5 | 1.5 | 5 | >5 | – | – | – | – | – | – |
| TN | ($mg L^{-1}$) | 1.410 | 2.460 | 1.787 | 0.407 | 1.000 | 1.880 | 1.334 | 0.311 | – | – | – | – | – | – | – | – | – | – |

(*Continued*)

Table 3 (*Continued*)

| Water-quality indicators | | Galyan regulator, the Galyan Stream | | | | Esiroğlu regulator, the Değirmendere Stream | | | | TSWQR (2015) | | | | TS 266 (2005) | | RCWIHC (2005) | EU (1998) | WHO (2004) | US EPA (2009) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Mean | SD | Min | Max | Mean | SD | Class I | Class II | Class III | Class IV | Class I–II Type I | Class II Type II | | | | |
| *o*–$PO_4^{3-}$–P | (mg $L^{-1}$) | 0.071 | 0.141 | 0.101 | 0.018 | 0.081 | 0.111 | 0.100 | 0.009 | – | – | – | – | – | – | – | – | – | – |
| TP | (mg $L^{-1}$) | – | – | – | – | – | – | – | – | <0.030 | 0.160 | 0.650 | >0.650 | – | – | – | – | – | – |
| MBAS | (mg $L^{-1}$) | N.D. | N.D | N.C. | N.C. | N.D. | 0.065 | N.C. | N.C. | – | – | – | – | – | – | – | – | – | – |
| TC | (mg $L^{-1}$) | 11.0 | 44.2 | 19.2 | 10.4 | 11.7 | 33.5 | 20.9 | 7.8 | – | – | – | – | – | – | – | – | – | – |
| TIC | (mg $L^{-1}$) | 10.4 | 43.5 | 18.3 | 10.2 | 11.4 | 33.5 | 20.3 | 8.0 | – | – | – | – | – | – | – | – | – | – |
| TOC | (mg $L^{-1}$) | <2.0 | 3.73 | N.C. | N.C. | <2.0 | 2.92 | N.C. | N.C. | – | – | – | – | N.A.C. | N.A.C. | N.A.C. | N.A.C. | – | – |
| COD | (mg $L^{-1}$) | 3.14 | 7.07 | 4.80 | 1.32 | 2.69 | 6.75 | 5.01 | 1.35 | <25 | 50 | 70 | >70 | – | – | – | – | – | – |
| $Al^{3+}$ | (µg $L^{-1}$) | N.D. | 28 | 11 | 10 | N.D. | 47 | 17 | 16 | ≤300 | ≤300 | 1,000 | >1,000 | 200 | 200 | 200 | 200 | – | 200 |
| $Cu^{2+}$ | (µg $L^{-1}$) | <10 | <10 | N.C. | N.C. | <10 | <10 | N.C. | N.C. | ≤20 | 50 | 200 | >200 | 100 | 2,000 | 2,000 | 2,000 | 2,000 | 1,000 |
| $Mn^{2+}$ | (µg $L^{-1}$) | 13 | 152 | 46 | 43 | 12 | 88 | 46 | 29 | ≤100 | 500 | 3,000 | >3,000 | 20 | 50 | 50 | 50 | 400 | 50 |
| Total Cr | (µg $L^{-1}$) | 11 | 27 | 18 | 4 | 7 | 22 | 17 | 5 | ≤20 | 50 | 200 | >200 | 50 | 50 | 50 | 50 | 50 | 100 |
| Total Fe | (µg $L^{-1}$) | 200 | 498 | 318 | 115 | 175 | 535 | 343 | 114 | ≤300 | 1,000 | 5,000 | >5,000 | 50 | 200 | 200 | 200 | – | 300 |

N.A.C.: no abnormal change.
N.C.: not calculated.
N.D.: not detected.

Table 4
Correlation matrices for the stream water-quality indicators monitored at the Esiroğlu and Galyan regulators

| Esiroğlu | *Q* | *t* | DO | pH | EC | T | TSS | $Ca^{2+}$ | WH | $F^-$ | $Cl^-$ | $NH_4^+$–N | $NO_3^-$–N | TN | TKN | *o*–$PO_4^{3-}$–P | TC | TIC | COD | $Al^{3+}$ | $Mn^{2+}$ | Total Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *t* | 0.096 | | | | | | | | | | | | | | | | | | | | | |
| | 0.793 | | | | | | | | | | | | | | | | | | | | | |
| DO | −0.240 | −0.952[b] | | | | | | | | | | | | | | | | | | | | |
| | 0.505 | 0.000 | | | | | | | | | | | | | | | | | | | | |
| pH | −0.876[b] | −0.206 | 0.256 | | | | | | | | | | | | | | | | | | | |
| | 0.001 | 0.568 | 0.475 | | | | | | | | | | | | | | | | | | | |
| EC | −0.901[b] | −0.166 | 0.232 | 0.961[b] | | | | | | | | | | | | | | | | | | |
| | 0.000 | 0.648 | 0.475 | 0.000 | | | | | | | | | | | | | | | | | | |
| T | 0.722[a] | −0.310 | 0.182 | −0.570 | −0.606 | | | | | | | | | | | | | | | | | |
| | 0.018 | 0.383 | 0.614 | 0.085 | 0.063 | | | | | | | | | | | | | | | | | |
| TSS | 0.750[a] | −0.140 | −0.062 | −0.768[a] | −0.736[a] | 0.704 | | | | | | | | | | | | | | | | |
| | 0.032 | 0.741 | 0.883 | 0.026 | 0.037 | 0.051 | | | | | | | | | | | | | | | | |
| $Ca^{2+}$ | −0.895[b] | −0.047 | 0.202 | 0.955[b] | 0.996[b] | −0.512 | −0.767[a] | | | | | | | | | | | | | | | |
| | 0.001 | 0.904 | 0.603 | 0.000 | 0.000 | 0.159 | 0.026 | | | | | | | | | | | | | | | |
| WH | −0.895[b] | −0.063 | 0.222 | 0.956[b] | 0.993[b] | −0.521 | −0.781[a] | 0.999[b] | | | | | | | | | | | | | | |
| | 0.001 | 0.871 | 0.566 | 0.000 | 0.000 | 0.150 | 0.022 | 0.000 | | | | | | | | | | | | | | |
| $F^-$ | −0.503 | 0.542 | −0.560 | 0.451 | 0.543 | −0.749[a] | −0.447 | 0.360 | 0.342 | | | | | | | | | | | | | |
| | 0.139 | 0.105 | 0.092 | 0.191 | 0.105 | 0.013 | 0.267 | 0.342 | 0.368 | | | | | | | | | | | | | |
| $Cl^-$ | −0.295 | −0.451 | 0.329 | 0.574 | 0.370 | 0.059 | 0.135 | 0.245 | 0.245 | −0.061 | | | | | | | | | | | | |
| | 0.409 | 0.191 | 0.353 | 0.083 | 0.293 | 0.871 | 0.750 | 0.525 | 0.526 | 0.868 | | | | | | | | | | | | |
| $NH_4^+$–N | 0.820[b] | 0.199 | −0.243 | −0.636[a] | −0.652[a] | 0.597 | 0.609 | −0.541 | −0.536 | −0.507 | −0.355 | | | | | | | | | | | |
| | 0.004 | 0.581 | 0.498 | 0.048 | 0.041 | 0.068 | 0.109 | 0.133 | 0.137 | 0.135 | 0.314 | | | | | | | | | | | |
| $NO_3^-$–N | −0.427 | −0.579 | 0.605 | 0.499 | 0.510 | 0.248 | −0.117 | 0.511 | 0.507 | −0.243 | 0.374 | −0.313 | | | | | | | | | | |
| | 0.218 | 0.079 | 0.064 | 0.142 | 0.132 | 0.490 | 0.782 | 0.159 | 0.164 | 0.499 | 0.287 | 0.379 | | | | | | | | | | |
| TN | −0.336 | −0.067 | 0.172 | 0.282 | 0.364 | −0.038 | −0.410 | 0.508 | 0.509 | −0.053 | −0.217 | −0.080 | 0.629 | | | | | | | | | |
| | 0.343 | 0.855 | 0.635 | 0.429 | 0.301 | 0.918 | 0.313 | 0.163 | 0.162 | 0.885 | 0.546 | 0.827 | 0.051 | | | | | | | | | |
| TKN | 0.161 | 0.626 | −0.546 | −0.307 | −0.233 | −0.331 | −0.256 | −0.092 | −0.085 | 0.229 | −0.689[a] | 0.295 | −0.525 | 0.332 | | | | | | | | |
| | 0.657 | 0.053 | 0.103 | 0.387 | 0.518 | 0.350 | 0.540 | 0.814 | 0.828 | 0.525 | 0.027 | 0.408 | 0.119 | 0.349 | | | | | | | | |
| *o*–$PO_4^{3-}$–P | 0.548 | −0.098 | −0.028 | −0.398 | −0.515 | 0.827[b] | 0.767[a] | −0.401 | −0.416 | −0.563 | 0.348 | 0.448 | 0.087 | −0.322 | −0.449 | | | | | | | |
| | 0.101 | 0.787 | 0.940 | 0.254 | 0.128 | 0.003 | 0.026 | 0.285 | 0.265 | 0.090 | 0.324 | 0.194 | 0.812 | 0.363 | 0.193 | | | | | | | |
| TC | −0.739[a] | −0.444 | 0.414 | 0.928[b] | 0.883[b] | −0.315 | −0.557 | 0.863[b] | 0.859[b] | 0.309 | 0.725[a] | −0.627 | 0.604 | 0.158 | −0.567 | −0.184 | | | | | | |
| | 0.015 | 0.198 | 0.234 | 0.000 | 0.001 | 0.375 | 0.152 | 0.003 | 0.003 | 0.386 | 0.018 | 0.052 | 0.064 | 0.662 | 0.087 | 0.610 | | | | | | |
| TIC | −0.687[a] | −0.474 | 0.424 | 0.903[b] | 0.833[b] | −0.273 | −0.483 | 0.799[b] | 0.796[a] | 0.264 | 0.791[b] | −0.602 | 0.577 | 0.094 | −0.604 | −0.122 | 0.994[b] | | | | | |
| | 0.028 | 0.167 | 0.222 | 0.000 | 0.003 | 0.446 | 0.225 | 0.010 | 0.010 | 0.462 | 0.006 | 0.065 | 0.081 | 0.796 | 0.065 | 0.737 | 0.000 | | | | | |
| COD | 0.429 | −0.014 | 0.049 | −0.399 | −0.273 | 0.505 | 0.097 | −0.163 | −0.168 | −0.313 | −0.501 | 0.522 | 0.217 | 0.180 | −0.068 | 0.130 | −0.340 | −0.376 | | | | |
| | 0.216 | 0.969 | 0.893 | 0.254 | 0.455 | 0.136 | 0.820 | 0.675 | 0.665 | 0.378 | 0.140 | 0.122 | 0.548 | 0.619 | 0.851 | 0.720 | 0.336 | 0.284 | | | | |

(*Continued*)

Table 4 (*Continued*)

| Esiroğlu | *Q* | *t* | DO | pH | EC | T | TSS | $Ca^{2+}$ | WH | $F^-$ | $Cl^-$ | $NH_4^+$–N | $NO_3^-$–N | TN | TKN | *o*–$PO_4^{3-}$–P | TC | TIC | COD | $Al^{3+}$ | $Mn^{2+}$ | Total Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Al^{3+}$ | 0.517 | −0.164 | 0.016 | −0.103 | −0.244 | 0.608 | 0.323 | −0.263 | −0.264 | −0.392 | 0.364 | 0.639 | 0.219 | −0.076 | −0.370 | 0.480 | 0.034 | 0.097 | 0.498 | | | |
| | 0.154 | 0.673 | 0.967 | 0.793 | 0.527 | 0.082 | 0.435 | 0.494 | 0.492 | 0.296 | 0.335 | 0.064 | 0.570 | 0.846 | 0.327 | 0.191 | 0.931 | 0.804 | 0.173 | | | |
| $Mn^{2+}$ | 0.450 | 0.097 | −0.283 | −0.016 | −0.072 | 0.295 | 0.287 | −0.113 | −0.115 | −0.003 | 0.131 | 0.697[a] | −0.035 | 0.191 | 0.269 | 0.148 | 0.021 | 0.056 | 0.104 | 0.597 | | |
| | 0.225 | 0.804 | 0.461 | 0.968 | 0.854 | 0.441 | 0.490 | 0.772 | 0.768 | 0.993 | 0.737 | 0.037 | 0.929 | 0.623 | 0.483 | 0.703 | 0.957 | 0.887 | 0.790 | 0.089 | | |
| Total Cr | 0.038 | −0.294 | 0.300 | 0.077 | 0.111 | 0.471 | 0.330 | 0.069 | 0.064 | −0.371 | 0.034 | 0.260 | 0.696[a] | 0.430 | −0.406 | 0.248 | 0.133 | 0.108 | 0.663 | 0.560 | 0.137 | |
| | 0.923 | 0.443 | 0.434 | 0.845 | 0.776 | 0.201 | 0.425 | 0.861 | 0.871 | 0.326 | 0.930 | 0.500 | 0.037 | 0.248 | 0.278 | 0.519 | 0.732 | 0.781 | 0.052 | 0.117 | 0.726 | |
| Total Fe | 0.705 | −0.361 | 0.166 | −0.610 | −0.426 | 0.764[a] | 0.467 | −0.468 | −0.479 | −0.425 | −0.289 | 0.612 | 0.444 | 0.365 | −0.079 | 0.280 | −0.340 | −0.349 | 0.737[a] | 0.534 | 0.556 | 0.582 |
| | 0.051 | 0.380 | 0.694 | 0.108 | 0.292 | 0.027 | 0.243 | 0.242 | 0.230 | 0.294 | 0.487 | 0.107 | 0.270 | 0.373 | 0.853 | 0.502 | 0.410 | 0.397 | 0.037 | 0.173 | 0.153 | 0.130 |
| Galyan | *t* | DO | pH | EC | T | TSS | $Ca^{2+}$ | WH | $F^-$ | $Cl^-$ | $NH_4^+$–N | $NO_3^-$–N | TN | TKN | *o*–$PO_4^{3-}$–P | TC | TIC | COD | $Al^{3+}$ | $Mn^{2+}$ | Total Cr | |
| DO | −0.963[b] | | | | | | | | | | | | | | | | | | | | | |
| | 0.000 | | | | | | | | | | | | | | | | | | | | | |
| pH | 0.180 | −0.300 | | | | | | | | | | | | | | | | | | | | |
| | 0.618 | 0.400 | | | | | | | | | | | | | | | | | | | | |
| EC | −0.142 | −0.037 | 0.837[b] | | | | | | | | | | | | | | | | | | | |
| | 0.696 | 0.919 | 0.003 | | | | | | | | | | | | | | | | | | | |
| T | −0.181 | 0.022 | 0.532 | 0.520 | | | | | | | | | | | | | | | | | | |
| | 0.616 | 0.952 | 0.114 | 0.124 | | | | | | | | | | | | | | | | | | |
| TSS | −0.097 | 0.058 | 0.634 | 0.556 | 0.959[b] | | | | | | | | | | | | | | | | | |
| | 0.819 | 0.891 | 0.091 | 0.152 | 0.000 | | | | | | | | | | | | | | | | | |
| $Ca^{2+}$ | −0.091 | 0.139 | 0.779[a] | 0.992[b] | 0.211 | 0.568 | | | | | | | | | | | | | | | | |
| | 0.816 | 0.721 | 0.013 | 0.000 | 0.585 | 0.142 | | | | | | | | | | | | | | | | |
| WH | −0.141 | 0.190 | 0.779[a] | 0.989[b] | 0.230 | 0.620 | 0.996[b] | | | | | | | | | | | | | | | |
| | 0.717 | 0.624 | 0.013 | 0.000 | 0.552 | 0.101 | 0.000 | | | | | | | | | | | | | | | |
| $F^-$ | 0.101 | −0.325 | 0.517 | 0.759[a] | 0.466 | 0.026 | −0.077 | −0.127 | | | | | | | | | | | | | | |
| | 0.782 | 0.360 | 0.126 | 0.011 | 0.175 | 0.952 | 0.844 | 0.745 | | | | | | | | | | | | | | |
| $Cl^-$ | −0.407 | 0.220 | 0.619 | 0.739[a] | 0.744[a] | 0.756[a] | 0.240 | 0.312 | 0.589 | | | | | | | | | | | | | |
| | 0.242 | 0.541 | 0.056 | 0.015 | 0.014 | 0.030 | 0.534 | 0.414 | 0.073 | | | | | | | | | | | | | |
| $NH_4^+$–N | −0.202 | 0.187 | −0.005 | −0.216 | 0.419 | 0.619 | −0.012 | 0.007 | −0.119 | 0.117 | | | | | | | | | | | | |
| | 0.576 | 0.604 | 0.989 | 0.549 | 0.228 | 0.102 | 0.976 | 0.987 | 0.743 | 0.747 | | | | | | | | | | | | |
| $NO_3^-$–N | −0.356 | 0.226 | 0.718[a] | 0.777[b] | 0.372 | 0.409 | 0.635 | 0.666 | 0.387 | 0.730[a] | −0.055 | | | | | | | | | | | |
| | 0.313 | 0.530 | 0.019 | 0.008 | 0.290 | 0.315 | 0.066 | 0.050 | 0.269 | 0.017 | 0.880 | | | | | | | | | | | |
| TN | −0.015 | −0.058 | 0.725[a] | 0.714[a] | 0.045 | −0.201 | 0.568 | 0.577 | 0.426 | 0.487 | −0.219 | 0.839[b] | | | | | | | | | | |
| | 0.968 | 0.874 | 0.018 | 0.020 | 0.902 | 0.634 | 0.111 | 0.104 | 0.220 | 0.153 | 0.543 | 0.002 | | | | | | | | | | |
| TKN | 0.632[a] | −0.502 | −0.229 | −0.353 | −0.616 | −0.565 | −0.204 | −0.239 | −0.071 | −0.608 | −0.228 | −0.575 | −0.037 | | | | | | | | | |
| | 0.050 | 0.139 | 0.524 | 0.317 | 0.058 | 0.144 | 0.599 | 0.536 | 0.846 | 0.062 | 0.526 | 0.082 | 0.919 | | | | | | | | | |

(*Continued*)

Table 4 (*Continued*)

| Galyan | *t* | DO | pH | EC | T | TSS | $Ca^{2+}$ | WH | $F^-$ | $Cl^-$ | $NH_4^+$–N | $NO_3^-$–N | TN | TKN | *o*–$PO_4^{3-}$–P | TC | TIC | COD | $Al^{3+}$ | $Mn^{2+}$ | Total Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *o*–$PO_4^{3-}$–P | −0.040 | 0.056 | −0.140 | −0.253 | 0.173 | 0.059 | −0.409 | −0.367 | −0.309 | 0.175 | −0.096 | −0.124 | −0.233 | −0.123 | | | | | | | |
| | 0.914 | 0.877 | 0.700 | 0.481 | 0.633 | 0.890 | 0.274 | 0.331 | 0.384 | 0.630 | 0.792 | 0.732 | 0.517 | 0.735 | | | | | | | |
| TC | −0.306 | 0.116 | 0.771[b] | 0.934[b] | 0.662[a] | 0.941[b] | 0.765[a] | 0.809[b] | 0.682[a] | 0.912[b] | −0.123 | 0.807[b] | 0.610 | −0.565 | −0.051 | | | | | | |
| | 0.390 | 0.749 | 0.009 | 0.000 | 0.037 | 0.000 | 0.016 | 0.008 | 0.030 | 0.000 | 0.735 | 0.005 | 0.061 | 0.089 | 0.889 | | | | | | |
| TIC | −0.323 | 0.132 | 0.734[a] | 0.921[b] | 0.606 | 0.884[b] | 0.701[a] | 0.752[a] | 0.678[a] | 0.913[b] | −0.183 | 0.825[b] | 0.635[a] | −0.561 | −0.021 | 0.994[b] | | | | | |
| | 0.363 | 0.717 | 0.016 | 0.000 | 0.063 | 0.004 | 0.035 | 0.019 | 0.031 | 0.000 | 0.612 | 0.003 | 0.049 | 0.092 | 0.954 | 0.000 | | | | | |
| COD | 0.093 | −0.088 | −0.382 | −0.530 | 0.278 | 0.347 | −0.532 | −0.526 | −0.173 | −0.061 | 0.576 | −0.296 | −0.470 | −0.162 | 0.211 | −0.351 | −0.359 | | | | |
| | 0.797 | 0.810 | 0.276 | 0.115 | 0.437 | 0.399 | 0.140 | 0.146 | 0.633 | 0.867 | 0.082 | 0.406 | 0.171 | 0.655 | 0.558 | 0.320 | 0.309 | | | | |
| $Al^{3+}$ | −0.412 | 0.365 | −0.616 | −0.549 | −0.120 | −0.229 | −0.523 | −0.500 | 0.222 | 0.123 | 0.400 | −0.147 | −0.237 | −0.099 | −0.268 | −0.286 | −0.239 | 0.488 | | | |
| | 0.271 | 0.334 | 0.077 | 0.126 | 0.759 | 0.585 | 0.148 | 0.171 | 0.567 | 0.753 | 0.286 | 0.706 | 0.538 | 0.801 | 0.485 | 0.455 | 0.535 | 0.182 | | | |
| $Mn^{2+}$ | 0.328 | −0.347 | 0.428 | 0.005 | 0.114 | 0.109 | −0.048 | −0.036 | 0.138 | 0.309 | 0.428 | 0.440 | 0.563 | 0.092 | 0.060 | 0.041 | 0.061 | 0.422 | 0.101 | | |
| | 0.388 | 0.361 | 0.250 | 0.989 | 0.770 | 0.797 | 0.902 | 0.926 | 0.723 | 0.419 | 0.250 | 0.236 | 0.114 | 0.813 | 0.878 | 0.916 | 0.875 | 0.257 | 0.795 | | |
| Total Cr | 0.382 | −0.401 | −0.034 | −0.346 | −0.312 | −0.402 | −0.381 | −0.398 | 0.232 | −0.196 | 0.134 | 0.165 | 0.411 | 0.308 | −0.047 | −0.466 | −0.400 | 0.414 | 0.271 | 0.810[b] | |
| | 0.311 | 0.285 | 0.930 | 0.362 | 0.413 | 0.323 | 0.311 | 0.289 | 0.549 | 0.613 | 0.730 | 0.671 | 0.272 | 0.421 | 0.904 | 0.206 | 0.287 | 0.257 | 0.480 | 0.008 | |
| Total Fe | 0.049 | −0.106 | 0.168 | −0.119 | 0.060 | 0.065 | −0.106 | −0.095 | −0.212 | 0.241 | 0.263 | 0.565 | 0.316 | −0.440 | 0.021 | 0.081 | 0.155 | 0.491 | 0.216 | 0.702[a] | 0.660 |
| | 0.901 | 0.785 | 0.667 | 0.760 | 0.877 | 0.878 | 0.787 | 0.807 | 0.583 | 0.533 | 0.494 | 0.113 | 0.408 | 0.236 | 0.957 | 0.836 | 0.690 | 0.180 | 0.577 | 0.035 | 0.053 |

Cells show the Pearson correlation coefficient and the corresponding *P* value.
[a]Correlation is significant at the 0.05 level (two tailed).
[b]Correlation is significant at the 0.01 level (two tailed).

with the international directives and guidelines (Table 3). Similarly, Bulut et al. [38] reported that the Galyan Stream was classified as high quality, based on a mean value of 7.80 varying between 7.50 and 8.00.

Taking into account the seasonal variations in the stream water pH and flow rate for Değirmendere, it was seen that the trends were just the opposite. A negative but strong correlation between stream water pH values and flow rates was found ($R$ = −0.876).

As a part of the study, the water-quality reports [49] of the Trabzon Metropolitan Municipality were examined in terms of pH. It was clearly seen that the waters from the drinking water treatment plants had a mean value of 7.72, varying between 7.35 and 7.92 (Table 5) and falling within the allowable pH range.

### *4.4. Dissolved oxygen*

The winter presenting the coldest stream temperatures brought about the higher DO concentrations: 11.07 and 10.70 mg $L^{-1}$, while the summer presenting the warmest stream temperatures gave rise to the lower DO concentrations: 8.99 and 8.87 mg $L^{-1}$ in the Değirmendere and Galyan streams, respectively. The annual mean values were calculated as 10.33 and 9.97 mg $L^{-1}$, respectively, showing a minor difference between the two stations. Based on DO concentrations, the waters of the Değirmendere and Galyan streams were classified as high quality [31]. Bulut et al. [38] reported similar concentrations of DO, with a mean value of 10.10 mg $L^{-1}$ varying between 8.40 and 10.90 mg $L^{-1}$, and also classified the Galyan Stream as high quality.

The Pearson correlation coefficients, $R$ = −0.952 for Değirmendere and −0.963 for Galyan, revealed that the stream water DOs were negatively but strongly correlated with the stream water temperatures. These are mainly because the solubility of oxygen in water is temperature-dependent that is to say cool water holds more DO than warm water. Bulut et al. [38] reported that there was a negative and strong correlation ($R$ = −0.852) between stream water DOs and temperatures for the Galyan Stream.

### *4.5. Electrical conductivity*

The EC values were lower during spring, 131.2 μS $cm^{-1}$ for Değirmendere and 105.1 μS $cm^{-1}$ for Galyan, and showed a steadily increasing trend throughout the study period. The higher EC values were during winter, 336 μS $cm^{-1}$ for the former and 393 μS $cm^{-1}$ for the latter. The annual mean EC values were calculated as 218 and 202 μS $cm^{-1}$, respectively, showing a minor difference between the two stations. With reference to the upper threshold value of 400 μS $cm^{-1}$ for EC, the both streams were classified as high quality [31]. Moreover, the permissible EC value is 2,500 μS $cm^{-1}$ at 20°C according to TS 266 [33]. The whole measurement results were well below the threshold value. Bulut et al. [38] reported that the annual mean EC value was 155.6 μS $cm^{-1}$ with a range of 90.3 to 244.1 μS $cm^{-1}$ for the Galyan Stream.

Taking into account the seasonal variations in the stream water EC and flow rate for Değirmendere, it was seen that the trends were just the opposite. Variations in EC are tied directly to seasonal variations in stream flow and water-quality condition. Lower spring conductivities are likely to be related to higher flows and more dilution, while higher winter conductivities are likely to be related to lower flows and more concentration. The Pearson correlation analysis revealed that the stream water EC values were negatively but strongly correlated with the flow rates, $R$ = −0.901 for Değirmendere, while positively and strongly correlated with the stream water pH values, $R$ = 0.961 for Değirmendere and 0.837 for Galyan. Bulut et al. [38] reported that there was a negative but strong correlation between the stream water EC values and the flow rates ($R$ = −0.782) for Galyan.

As a part of the study, the water-quality reports [49] of the Trabzon Metropolitan Municipality were examined in terms of EC. It was clearly seen that the waters from the drinking water treatment plants had a mean value of 162 μS $cm^{-1}$, varying between 110 and 230 μS $cm^{-1}$ (Table 5) and this threshold.

### *4.6. Total dissolved solids*

The seasonal TDS concentrations showed a steadily increasing trend throughout the study period. The TDS values were lower during spring, 62.2 mg $L^{-1}$ for Değirmendere and 49.6 mg $L^{-1}$ for Galyan, and were higher during winter, 161.4 mg $L^{-1}$ for the former and 189.6 mg $L^{-1}$ for the latter. The annual mean TDS values were calculated as 104.0 and 96.5 mg $L^{-1}$, respectively, showing a minor difference between the two stations. No classification for TDS is available in the TSWQR [31]. No health-based guideline value is proposed for TDS nationally [32,33] and internationally [34,35] except for the US EPA [36] in which the allowable concentration is 500 mg $L^{-1}$.

### *4.7. Turbidity*

The stream turbidity reached an average maximum value of 107 NTU during spring 2010 in Değirmendere. As time went by, it tended to be lower, and an average minimum value of 51 NTU was determined during winter. Unlike the Değirmendere Stream, an average minimum value of 102 NTU was determined during spring 2010 in the Galyan Stream. In time, it tended to be higher and reached an average maximum value of 219 NTU during winter. The annual mean values were calculated as 72 and 158 NTU, respectively. At first sight, it is surprising that each stream having similar watershed characteristics showed dissimilar trend although each stream was expected to show similar trend. The various construction activities in the Galyan Stream watershed such as dam, soil-saving dams, levees and relocation of roads impacted the water quality severely. As a result of these activities, an increase of 119% in the stream turbidity was determined in comparison with the Değirmendere Stream. Furthermore, Bulut et al. [38] reported that the stream turbidity varied between 1.9 and 8.1 NTU in Galyan during one-year period from April 2004 to March 2005.

No classification for the stream turbidity is available in the TSWQR [31]. The permissible limit value is 5 NTU according to TS 266 [33]. However, the upper threshold value is 1 NTU if drinking water is obtained by treating the stream water. Considering the water-quality reports [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality, it was clearly seen that the treated waters had a mean value of 0.82 NTU, ranging from 0.28 to 1.35 NTU (Table 5) below this threshold.

Table 5
The monthly mean values of the water-quality indicators based on the water-quality reports from the drinking water treatment plants of the Trabzon Metropolitan Municipality (TİSKİ 2016)

| Monitoring period | Water-quality indicators | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | EC (µS $cm^{-1}$) | TDS (mg $L^{-1}$) | $T$ (NTU) | WH (°fH) | $Ca^{2+}$ (mg $L^{-1}$) | $Mg^{2+}$ (mg $L^{-1}$) | $F^-$ (mg $L^{-1}$) | $Cl^-$ (mg $L^{-1}$) | $SO_4^{2-}$ (mg $L^{-1}$) | $NH_4^+$ (mg $L^{-1}$) | $NO_2^-$ (mg $L^{-1}$) | $NO_3^-$–N (mg $L^{-1}$) | TOC (mg $L^{-1}$) | $Al^{3+}$ (µg $L^{-1}$) | $Cu^{2+}$ (µg $L^{-1}$) | $Mn^{2+}$ (µg $L^{-1}$) | Total Cr (µg $L^{-1}$) | Total Fe (µg $L^{-1}$) |
| 2016 Feb | 7.37 | 211 | – | 1.30 | 8.85 | 30.00 | 3.20 | 0.090 | 9.90 | 10.80 | <0.005 | <0.005 | 1.07 | – | 50 | 40 | 14 | 9 | 4 |
| 2016 Jan | 7.62 | 183 | 76 | 0.97 | 7.10 | 23.40 | 3.00 | 0.048 | 6.75 | 6.50 | <0.005 | <0.005 | 0.75 | 0.6 | 30 | 20 | 10 | <1 | 10 |
| 2015 Dec | 7.80 | 165 | 88 | 0.60 | 7.60 | 25.00 | 3.70 | 0.036 | 14.00 | 7.00 | <0.005 | <0.005 | 1.60 | 0.8 | 37 | 20 | 6 | <1 | 13 |
| 2015 Nov | 7.43 | 165 | 80 | 1.08 | 7.30 | 20.20 | 8.80 | 0.010 | 6.08 | 7.50 | <0.005 | <0.005 | 1.10 | 1.2 | 46 | 20 | 1 | <1 | 31 |
| 2015 Oct | 7.53 | 146 | 70 | 1.00 | 6.90 | 21.20 | 3.96 | 0.015 | 4.60 | 5.00 | <0.005 | <0.005 | 1.10 | 1.9 | 27 | 20 | 10 | <1 | 8 |
| 2015 Sept | 7.90 | 230 | 90 | 0.81 | 12.00 | 22.00 | 15.60 | 0.017 | 5.00 | 13.00 | <0.005 | <0.005 | 1.20 | 1.8 | 47 | 22 | 1 | <1 | 2 |
| 2015 Aug | 7.70 | 165 | 90 | 1.06 | 10.00 | 18.00 | 13.20 | 0.015 | 6.00 | 12.00 | <0.005 | <0.005 | 1.10 | 1.4 | 42 | 28 | 8 | <1 | 9 |
| 2015 July | 7.64 | 150 | 82 | 1.09 | 7.70 | 16.00 | 8.80 | 0.020 | 9.00 | 11.00 | <0.005 | <0.005 | 1.10 | 1.2 | 58 | 23 | 4 | <1 | 8 |
| 2015 June | 7.45 | 115 | 78 | 0.80 | 5.30 | 15.00 | 3.60 | 0.020 | 5.90 | 5.00 | <0.005 | <0.005 | 0.90 | 0.8 | 52 | 10 | 6 | <1 | 14 |
| 2015 May | 7.60 | 110 | 76 | 0.52 | 5.20 | 20.00 | 3.10 | 0.030 | 5.30 | 6.00 | <0.005 | <0.005 | 1.50 | 0.4 | 45 | <10 | 4 | <1 | 7 |
| 2015 Apr | 7.69 | 135 | 70 | 0.79 | 7.90 | 22.00 | 5.80 | 0.060 | 6.00 | 13.00 | <0.005 | <0.005 | 1.30 | 0.5 | 50 | <10 | 7 | <1 | 6 |
| 2015 Mar | 7.90 | 165 | 77 | 0.28 | 8.00 | 25.00 | 4.60 | 0.080 | 7.00 | 18.00 | <0.005 | <0.005 | 1.20 | 0.6 | 21 | <10 | 7 | <1 | 8 |
| 2015 Feb | 7.90 | 160 | 70 | 0.70 | 9.00 | 27.00 | 5.30 | – | 7.80 | 10.00 | <0.005 | <0.005 | 1.90 | – | 15 | – | – | – | 9 |
| 2015 Jan | 7.80 | 180 | 75 | 0.90 | 8.20 | 24.00 | 5.30 | – | 7.30 | 12.00 | <0.005 | <0.005 | 1.50 | – | 20 | – | – | – | 5 |
| 2014 Dec | 7.75 | 195 | – | 1.30 | 8.80 | 33.00 | – | – | 7.50 | 13.00 | <0.005 | <0.005 | 1.20 | – | 35 | – | – | – | 2 |
| 2014 Nov | 7.35 | 193 | – | 1.35 | 9.35 | 35.50 | – | – | 8.10 | 13.60 | <0.005 | <0.005 | 1.75 | – | 67 | – | – | – | 7 |
| 2014 Oct | 7.40 | 216 | – | 1.33 | 10.40 | 34.25 | – | – | 8.30 | 11.25 | <0.005 | <0.005 | 1.77 | – | 110 | – | – | – | 36 |
| 2014 Sept | 7.73 | 176 | – | 0.73 | 8.70 | 27.30 | – | – | 7.47 | 7.43 | <0.005 | <0.005 | 2.05 | – | 70 | – | – | – | 10 |
| 2014 Aug | 7.90 | 171 | – | 0.49 | 8.00 | 26.40 | – | – | 11.50 | 8.20 | <0.005 | <0.005 | 1.60 | – | 27 | – | – | – | 3 |
| 2014 July | 7.90 | 167 | – | 0.57 | 8.30 | 29.00 | – | – | 19.00 | 10.00 | <0.005 | <0.005 | 2.30 | – | 36 | – | – | – | 14 |
| 2014 June | 7.85 | 132 | – | 0.63 | 7.60 | 29.50 | – | – | 8.60 | 9.20 | <0.005 | <0.005 | 2.25 | – | 28 | – | – | – | 7 |
| 2014 May | 7.92 | 124 | – | 0.65 | 7.50 | 24.30 | – | – | 9.72 | 9.50 | <0.005 | <0.005 | 2.00 | – | 30 | – | – | – | 6 |
| 2014 Apr | 7.85 | 128 | – | 0.56 | 9.10 | 27.20 | – | – | 8.95 | 15.20 | <0.005 | <0.005 | 1.60 | – | 20 | – | – | – | 10 |
| 2014 Mar | 7.87 | 150 | – | 0.59 | 9.80 | 28.00 | – | – | 10.00 | 13.75 | <0.005 | <0.005 | 1.97 | – | 20 | – | – | – | 12 |
| Average | 7.70 | 164 | 79 | 0.84 | 8.28 | 25.13 | 6.28 | 0.037 | 8.32 | 10.33 | <0.005 | <0.005 | 1.49 | 1.0 | 41 | <19 | 7 | <1 | 13 |

### 4.8. Total suspended solids

Like the stream turbidity, the total suspended solids in Değirmendere reached an average maximum value of 48.2 mg $L^{-1}$ in spring 2010 when the flow rates were also higher. With the passing of time, TSS tended to be lower like the flow rate, and an average minimum value of 27.1 mg $L^{-1}$ was determined in the winter. Unlike the Değirmendere Stream, an average minimum value of 30.6 mg $L^{-1}$ was determined in the Galyan Stream during spring 2010. In time, it tended to be higher and reached an average maximum value of 148.2 mg $L^{-1}$ during winter. The annual mean values were calculated as 38.3 and 86.5 mg $L^{-1}$, respectively, showing a big difference. As a result of the construction activities in the Galyan Stream watershed, an increase of 126% in the TSS, as such in the stream turbidity, was determined in comparison with the Değirmendere Stream. No classification for the TSS is available in the TSWQR [31].

### 4.9. Calcium ion

The stream calcium ion concentrations showed a steadily increasing trend similar to the stream water EC and pH values throughout the study period. The minimum values of $Ca^{2+}$ were 30.0 mg $L^{-1}$ for Değirmendere and 24.4 mg $L^{-1}$ for Galyan in spring. The maximum concentrations of $Ca^{2+}$ were 62.7 mg $L^{-1}$ for the former and 53.5 mg $L^{-1}$ for the latter in the winter. The annual mean values were calculated as 41.7 and 34.4 mg $L^{-1}$, respectively. It is thought that the variations in the $Ca^{2+}$ are tied directly to seasonal changes in the stream flow. Low spring $Ca^{2+}$ values are likely to be related to higher flows and more dilution. No classification for $Ca^{2+}$ is available in the TSWQR [31]. Both national [32,33] and international guidelines [34–36] do not refer to $Ca^{2+}$.

Pearson correlation analysis revealed that the stream water $Ca^{2+}$ content was negatively but strongly associated with the flow rate, $R = -0.895$ for the Değirmendere Stream, while positively and strongly correlated with the stream water EC, $R = 0.996$ for the Değirmendere Stream and 0.992 for the Galyan Stream, as well as the stream water pH, $R = 0.961$ for the former and 0.837 for the latter.

### 4.10. Magnesium ion

The magnesium ion concentrations were under measuring range throughout the study period due to the lower limit of 3 mg $L^{-1}$ except for the values of 3.95 and 4.46 mg $L^{-1}$ on November and December 2010, respectively, for Değirmendere and 3.14 mg $L^{-1}$ on December 2010 for Galyan. No classification for $Mg^{2+}$ is available in the TSWQR [31]. Both national [32,33] and international guidelines [34–36] do not refer to $Mg^{2+}$.

### 4.11. Water hardness

The hardness values were low, 4.20 °dH for Değirmendere and 3.42 °dH for Galyan, in spring. Like the water pH, EC, and $Ca^{2+}$ content, the hardness showed a steadily increasing trend in direct proportion to the conductivity throughout the study period. The hardness values were high, 9.82 °dH for the former and 8.23 °dH for the latter, in the winter. The annual mean values were calculated as 6.17 and 4.96 °dH, respectively. No classification for hardness is available in the TSWQR [31]. No health-based guideline value is proposed for hardness nationally [32,33] and internationally [34–36].

Hardness in water is usually expressed as the equivalent quantity of calcium carbonate ($CaCO_3$), and 1 °dH corresponds to 17.9 mg $L^{-1}$ $CaCO_3$ [35,50]. In this way, the annual mean WH values of 6.17 and 4.96 °dH can be converted to 110 and 89 mg $L^{-1}$ $CaCO_3$, respectively. Water with a hardness range of 0 to 75 mg $L^{-1}$ as $CaCO_3$ is classified as soft water, whereas water with a hardness range of 75–150 mg $L^{-1}$ as $CaCO_3$ is classified as moderately hard water [50]. Therefore, the stream waters are qualified as moderately hard water for both stations.

On the one hand, the hardness values were negatively but strongly associated with the flow rates ($R = -0.895$ for Değirmendere) as such in the stream water $Ca^{2+}$ content. This was mainly because the hardness values were positively and strongly correlated with the $Ca^{2+}$ content ($R = 0.999$ for Değirmendere and 0.996 for Galyan). On the other hand, the hardness values were positively and strongly correlated with the stream water pH values ($R = 0.956$ for Değirmendere and 0.779 for Galyan) and the stream water EC values ($R = 0.993$ for Değirmendere and 0.989 for Galyan). This was expected, because conductivity of water depends on type and concentration of the dissolved ions in water and increases together with any increase in dissolved salt concentration. Bulut et al. [38] reported that there was a negative but strong correlation between the hardness values and the stream flow rates ($R = -0.730$) and positive and strong correlation between the hardness values and the stream water EC values ($R = 0.915$) for Galyan.

### 4.12. Fluoride ion

The fluoride ion concentrations were at their lowest in spring, 0.098 mg $L^{-1}$ for Değirmendere and 0.163 mg $L^{-1}$ for Galyan. The concentrations were at their highest in autumn, 0.222 mg $L^{-1}$ for Değirmendere, and winter, 0.275 mg $L^{-1}$ for Galyan. The annual mean values were calculated as 0.180 and 0.203 mg $L^{-1}$, respectively, in the Değirmendere and Galyan streams. However, the treated waters had lower $F^-$ concentrations, varying between 0.010 and 0.080 mg $L^{-1}$, than the surface waters did, considering the water-quality reports [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality.

On the one hand, the water from the Değirmendere and Galyan streams are classified as high quality regarding the annual mean $F^-$ concentrations considering the upper threshold value of 1 mg $L^{-1}$ [31]. On the other hand, both streams can be also regarded as in the fluoride-poor water resources with reference to national [32,33] and international [34–36] directives and guidelines. According to WHO [35], the minimum $F^-$ concentration in drinking water should be approximately 0.5 mg $L^{-1}$ with an optimal range of 0.5–1.5 mg $L^{-1}$. In fact, fluoride is not essential for human growth and development but is helpful in the prevention of dental caries.

### 4.13. Chloride ion

The winter presented the relatively highest $Cl^-$ concentrations: 5.097 and 6.265 mg $L^{-1}$, while the autumn the lowest $Cl^-$ concentrations of 1.854 and 2.273 mg $L^{-1}$ in the Değirmendere and Galyan streams, respectively. The annual mean $Cl^-$ values were calculated as 3.518 and 3.265 mg $L^{-1}$, respectively, showing a minor difference between the two streams. No classification for $Cl^-$ is available in the TSWQR [31]. The permissible concentration of $Cl^-$ is 250 mg $L^{-1}$ in RCWIHC [32] and TS 266 [33], which complying with the international directives and guidelines (Table 3). Consequently, the $Cl^-$ concentrations measured throughout the study period are well below the permissible levels suggested or mandated by several references [32–36].

Considering the water-quality reports [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality, it was clearly seen that the treated waters had a mean value of 8.32 mg $L^{-1}$ $Cl^-$, ranging from 4.60 to 19.00 mg $L^{-1}$ $Cl^-$ (Table 5). These results revealed that the treated waters had higher $Cl^-$ concentration than the surface waters did. It has been thought that these higher concentrations were due to polyaluminum chloride used for coagulation and flocculation.

### 4.14. Sulfate ion

The sulfate ion concentrations were well under measuring range throughout the study period due to the lower limit of 40 mg $L^{-1}$ except for the value of 50.1 mg $L^{-1}$ for the Galyan Stream in January 2011. Similarly, the water-quality reports [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality reveal that the treated stream waters have a mean value of 10.33 mg $L^{-1}$ $SO_4^{2-}$ ranging from 5.00 to 18.00 mg $L^{-1}$ $SO_4^{2-}$ (Table 5). No classification for $SO_4^{2-}$ is available in the TSWQR [31]. The permissible concentration of $SO_4^{2-}$ is 250 mg $L^{-1}$ in the national regulation [32] and standard [33], complying with the international directives and guidelines (Table 3). Consequently, it is obvious that the $SO_4^{2-}$ concentrations of the stream waters are well below the permissible levels suggested or mandated by several references [32–36].

### 4.15. Ammonium nitrogen

The $NH_4^+$–N concentrations were at their lowest in the winter, 0.056 mg $L^{-1}$ for Değirmendere and 0.081 mg $L^{-1}$ for Galyan. The concentrations were at their highest in the summer, 0.107 mg $L^{-1}$ for Değirmendere and 0.119 mg $L^{-1}$ for Galyan. The annual mean $NH_4^+$–N values were calculated as 0.086 and 0.106 mg $L^{-1}$, respectively. Contrary to the initial expectations, the Galyan Stream had more concentration of $NH_4^+$–N at the rate of 23% when compared with the Değirmendere Stream while the untreated wastewater impacted urban stream was actually Değirmendere. The area around Trabzon is world-renowned for the production of hazelnuts, and calcium ammonium nitrate (CAN), an inorganic fertilizer known as nitro-limestone, has been widely used in the stream Galyan watershed where hazelnut has been intensely cultivated compared with the stream Değirmendere watershed.

The waters from the Değirmendere and Galyan streams were classified as high quality [31] regarding the mean values for $NH_4^+$–N. The permissible concentration of $NH_4^+$ is 0.500 mg $L^{-1}$ (0.388 mg $L^{-1}$ $NH_4^+$–N) in RCWIHC [32] and TS 266 [33] complying with the value of the Council Directive 98/83/EC [34]. Therefore, the $NH_4^+$–N concentrations throughout the whole year were compatible with the proposed values.

Considering the water-quality reports [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality, it was clearly seen that the treated waters had a $NH_4^+$–N concentration of <0.005 mg $L^{-1}$. It has been thought that the lower concentrations were due to nitrification being a process of ammonium ions biochemical oxidation to nitrates.

### 4.16. Nitrite nitrogen

Considering the Galyan Stream, the $NO_2^-$–N concentrations were under measuring range throughout the study period due to the lower limit of 0.002 mg $L^{-1}$ except for the value of 0.002 mg $L^{-1}$ in July 2010. In the Değirmendere Stream, $NO_2^-$–N concentration was at its lowest value, <0.002 mg $L^{-1}$, in spring, and at its highest value, 0.010 mg $L^{-1}$, in autumn; the annual mean being calculated as 0.005 mg $L^{-1}$.

The waters from the Değirmendere and Galyan streams were classified as high quality [31] regarding the mean values for $NO_2^-$–N. The allowable concentration for $NO_2^-$ is 0.500 mg $L^{-1}$ (0.152 mg $L^{-1}$ $NO_2^-$–N) in the RCWIHC [32] and the TS 266 [33], which complies with the Council Directive 98/83/EC [34]. Given that WHO guideline value for $NO_2^-$ is 3 mg $L^{-1}$ (0.913 mg $L^{-1}$ $NO_2^-$–N), moreover the maximum contaminant level for $NO_2^-$–N in drinking water by the US EPA is 1.000 mg $L^{-1}$, the $NO_2^-$–N concentrations monitored throughout the study period are within the permissible levels suggested or mandated by these references [32–36].

Considering the water-quality reports from March 2015 to February 2016 [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality, it was clearly seen that the treated waters had a $NO_2^-$ concentration of <0.005 mg $L^{-1}$.

### 4.17. Nitrate nitrogen

Unlike $NH_4^+$–N, the concentrations of $NO_3^-$–N were at their maximum values in the winter, 1.200 mg $L^{-1}$ for Değirmendere and 2.025 mg $L^{-1}$ for Galyan. The concentrations were at their lowest values in the summer, 0.476 mg $L^{-1}$ for Değirmendere and 0.881 mg $L^{-1}$ for Galyan. The annual mean $NO_3^-$–N values were calculated as 0.817 and 1.190 mg $L^{-1}$, respectively. The waters from the streams were classified as high quality [31] regarding the mean values. The allowable $NO_3^-$ concentration is 50 mg $L^{-1}$ (11.295 mg $L^{-1}$ $NO_3^-$–N) with reference to the RCWIHC [32], which complies with the national standard [33], and international directive [34] and guideline [35]. In addition, the maximum contaminant level for $NO_3^-$–N in drinking water by the US EPA is 10 mg $L^{-1}$. Consequently, the $NO_3^-$–N concentrations measured throughout the study period are within the permissible levels mandated or proposed by the several references mentioned above.

The fact that the Galyan Stream having also more concentration of $NO_3^-$–N at the rate of 46% similar to the $NH_4^+$–N concentration than the Değirmendere Stream was unexpected at the beginning of this study. Yilmaz and Usta [51] reported that alder is the dominant tree species in the broad-leaved forests that cover 67.3% of the Galyan Stream watershed.

They asserted that the amount of nitrogen is expected to be at a relatively higher level in such watershed soils because alder has the ability to fix atmospheric nitrogen in the soil with its roots. Similarly, Goldman [52], Binkley et al. [53], and Stottlemyer and Toczydlowski [54] asserted that alter stands can influence nitrogen concentrations of adjacent streams and lakes. As a result, it can be said that this higher concentration of $NO_3^-$–N in this watershed is mainly due to the alter stands and partially to the CAN that is used for hazelnut cultivation.

On the other hand, considering the water-quality reports [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality, the treated waters had higher $NO_3^-$–N concentrations, varying between 0.750 and 2.300 mg $L^{-1}$, than the surface waters did. It has been thought that the higher concentrations were due to nitrification.

### 4.18. Total Kjeldahl nitrogen

Like $NH_4^+$–N, the TKN concentrations were at their lowest values in the winter, 0.310 and 0.400 mg $L^{-1}$, and at their highest values in the summer, 0.727 and 0.898 mg $L^{-1}$, respectively, in the Değirmendere and Galyan streams. The annual mean TKN values were calculated as 0.512 and 0.597 mg $L^{-1}$, respectively, showing a minor difference between the two stations. The waters from the streams were classified as slightly polluted [31] in terms of the mean values.

### 4.19. Total nitrogen

Like $NO_3^-$–N, the TN concentrations were at their highest values in the winter, 1.515 mg $L^{-1}$ for Değirmendere and 2.425 mg $L^{-1}$ for Galyan, and at their lowest values in the summer, 1.205 mg $L^{-1}$ for Değirmendere, and spring, 1.497 mg $L^{-1}$ for Galyan. The annual mean values were calculated as 1.334 and 1.787 mg $L^{-1}$, respectively, showing a minor difference between the two stations, and $NO_3^-$–N constituted 61% and 67% of TN, respectively. No classification for TN is available in the TSWQR [31].

The Pearson correlation coefficients, where $R$ = 0.629 for Değirmendere and 0.839 for Galyan, revealed that TN was positively and significantly correlated with $NO_3^-$–N.

### 4.20. Orthophosphate phosphorus

The $o$-$PO_4^{3-}$–P values were at their relatively lowest concentrations in the winter, 0.097 mg $L^{-1}$ for Değirmendere, and in autumn, 0.092 mg $L^{-1}$ for Galyan. The $o$-$PO_4^{3-}$–P values were at their relatively highest concentrations in the summer, 0.103 mg $L^{-1}$ for the former, and in spring, 0.109 mg $L^{-1}$ for the latter. The annual mean values were calculated as 0.100 and 0.101 mg $L^{-1}$, respectively. No classification for $o$-$PO_4^{3-}$–P is available in the TSWQR [31]. With reference to the classification of the TSWQR regarding total $PO_4^{3-}$–P, the waters from the streams are classified as slightly polluted. This is not surprising since NPK compound fertilizer (compound fertilizer containing the elements: N, P and K) as well as CAN and occasionally manure are applied in each watershed for hazelnut cultivation.

Bulut et al. [34] had reported a little lower concentrations of $o$-$PO_4^{3-}$, varying between 0.060 and 0.530 mg $L^{-1}$ (0.019 and 0.173 mg $L^{-1}$ $o$-$PO_4^{3-}$–P), and classified the Galyan Stream as slightly polluted regarding an annual mean concentration of 0.210 mg $L^{-1}$ (0.068 mg $L^{-1}$ $o$-$PO_4^{3-}$–P).

### 4.21. Methylene blue active substances

The MBAS concentrations were under measuring range during the period of this study due to the lower limit of 0.050 mg $L^{-1}$ except for the value 0.065 mg $L^{-1}$ in the Galyan Stream in July 2010. No classification for MBAS is available in the TSWQR [31]. Both national [32,33] and international guidelines [34–36] do not refer to MBAS.

On the other hand, Bulut et al. [38] had reported higher concentrations of MBAS varying between 0.330 and 0.530 mg $L^{-1}$, and classified the Galyan Stream as polluted water, based on an annual mean concentration of 0.380 mg $L^{-1}$ with reference to the TWPCR [31].

### 4.22. Total carbon

The TC values were at their lowest concentrations in spring, 14.7 mg $L^{-1}$ for Değirmendere and 12.4 mg $L^{-1}$ for Galyan, and showed a steadily increasing trend throughout the study period. The higher TC values were during winter, 32.9 mg $L^{-1}$ for the former and 35.6 mg $L^{-1}$ for the latter. The annual mean values were calculated as 20.9 and 19.2 mg $L^{-1}$, respectively, showing a minor difference between the two stations. No classification for TC is available in the TSWQR [31].

### 4.23. Total inorganic carbon

The TIC values were at their lowest concentrations in spring, 14.3 mg $L^{-1}$ for Değirmendere and 12.2 mg $L^{-1}$ for Galyan, and showed a steadily increasing trend throughout the study period. Their higher values were during winter, 32.8 mg $L^{-1}$ for the former and 35.1 mg $L^{-1}$ for the latter. The annual mean values were calculated as 20.3 and 18.3 mg $L^{-1}$, respectively, showing a minor difference between the two stations. It was clearly seen that TC and TIC content exhibited almost the same trend throughout the period of study, and also the Pearson correlation coefficients, $R$ = 0.994 for each stream, revealed this trend. It was recognized that TIC constituted the most part of TC, which was 97% for Değirmendere and 96% for Galyan. Classification for TIC is not available in the TSWQR [31].

### 4.24. Total organic carbon

The TOC concentrations were under measuring range throughout the study period due to the lower limit of 2 mg $L^{-1}$ for each stream except for the values of 2.92 mg $L^{-1}$ in the Değirmendere Stream in September 2010 and 3.73 mg $L^{-1}$ in the Galyan Stream in November 2010. Similarly, the water-quality reports [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality revealed that the treated waters had lower TOC concentrations varying between 0.4 and 1.9 mg $L^{-1}$. No classification for TOC is available in the TSWQR [31]. No health-based guideline value is proposed for TOC nationally [32,33] and internationally [34–36].

*4.25. Chemical oxygen demand*

The COD values were at their lowest concentrations in the winter, 3.79 mg $L^{-1}$ for Değirmendere and 3.40 mg $L^{-1}$ for Galyan. The COD value was at its highest concentration in spring, 5.91 mg $L^{-1}$ for Değirmendere, whereas it was highest as being 5.63 mg $L^{-1}$ in the summer for Galyan. The annual mean values were calculated as 5.01 and 4.80 mg $L^{-1}$, respectively, showing a minor difference between these stations. The waters from the streams were classified as high quality [31] considering the upper threshold value of <25 mg $L^{-1}$ for COD. Similarly, Bulut et al. [38] classified the Galyan Stream as high quality, based on an annual mean COD concentration of 6.90 mg $L^{-1}$.

*4.26. Aluminum ion*

The lowest concentrations of $Al^{3+}$ were 4 and 5 μg $L^{-1}$, respectively, in autumn in the Değirmendere and Galyan streams. The relatively highest concentrations of $Al^{3+}$ were 26 μg $L^{-1}$ in the summer in the Değirmendere Stream and 18 μg $L^{-1}$ in spring in the Galyan Stream. The annual mean values were calculated as 17 and 11 μg $L^{-1}$, respectively. The waters from the streams are classified as high quality [31] considering the upper threshold value of 300 μg $L^{-1}$ for $Al^{3+}$. Similarly, Bulut et al. [38] classified the Galyan Stream as high quality, based on an annual mean $Al^{3+}$ concentration of 27.7 μg $L^{-1}$ by the graphite furnace atomic absorption spectrometer (GFAAS). The permissible concentration of $Al^{3+}$ is 200 μg $L^{-1}$ regarding national references [32,33] as well as international directives and guidelines [34–36], but still the $Al^{3+}$ concentrations measured throughout the study period are far below the permissible levels suggested or mandated by these references.

Considering the water-quality reports [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality, it was seen that the treated waters have a mean $Al^{3+}$ concentration of 41 μg $L^{-1}$, fluctuating between 15 and 110 μg$L^{-1}$ (Table 5). These results revealed that the treated waters had higher $Al^{3+}$ concentration than the surface waters did, but they had high quality. It has been thought that the more concentrations were due to aluminum sulfate and polyaluminum chloride used for coagulation and flocculation.

*4.27. Copper ion*

The concentrations of $Cu^{2+}$ were under measuring range throughout the study period due to the lower limit of 10 μg $L^{-1}$ for each stream. The waters from the streams are classified as high quality [31] with reference to the upper threshold value of 20 μg $L^{-1}$. Similarly, Bulut et al. [38] classified the Galyan Stream as high quality, based on the annual mean $Cu^{2+}$ concentration of 5.5 μg $L^{-1}$ by GFAAS.

Taking into account the water-quality reports [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality, it was surprising to see that the treated waters had a mean $Cu^{2+}$ concentration of 19 μg $L^{-1}$, ranging from <10 to 40 μg $L^{-1}$ (Table 5). These results revealed that the treated waters had higher $Cu^{2+}$ concentration than the surface waters did. However, the permissible concentration of $Cu^{2+}$ in drinking water is 2,000 μg $L^{-1}$ regarding national references [32,33] as well as international directives and guidelines except for the US EPA, in which the allowable concentration for $Cu^{2+}$ is 1,000 μg $L^{-1}$ (Table 3). Consequently, both the treated waters and the stream waters had $Cu^{2+}$ concentration being far below the permissible levels suggested or mandated by these references.

*4.28. Manganese ion*

The lowest concentrations of $Mn^{2+}$ were 27 and 26 μg $L^{-1}$ in autumn, and the highest concentrations of $Mn^{2+}$ were 71 and 94 μg $L^{-1}$, respectively, in the summer in the Değirmendere and Galyan streams. The annual mean values were calculated as 46 μg $L^{-1}$ for each stream. The waters from the streams are classified as high quality [31] considering the upper threshold value of 100 μg $L^{-1}$. However, the permissible concentration of $Mn^{2+}$ in drinking water is 50 μg $L^{-1}$ regarding national references [32,33] as well as international directives and guidelines except for WHO [35], in which the permissible concentration is 400 μg $L^{-1}$ (Table 3). The $Mn^{2+}$ concentrations measured throughout the period of study exceeded the permissible levels suggested or mandated by these references except for WHO [35].

Considering the water-quality reports from March 2015 to February 2016 [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality, it was clearly seen that the treated waters had a high quality with a mean value of 7 μg $L^{-1}$ $Mn^{2+}$, varying between <1 and 14 μg $L^{-1}$ (Table 5) and falling within the allowable $Mn^{2+}$ range.

*4.29. Total chromium*

Total Cr values were at their lowest concentrations in the summer, 15 μg $L^{-1}$ for Değirmendere, and in autumn, 16 μg $L^{-1}$ for Galyan. Total Cr values were at their highest concentrations in the winter, 21 μg $L^{-1}$ for the former, and in the summer, 22 μg $L^{-1}$ for the latter. The annual mean values were calculated as 17 and 18 μg $L^{-1}$, respectively. The waters from the streams are classified as high quality [31] with reference to the upper threshold value of 20 μg $L^{-1}$ for total Cr. However, Bulut et al. [38] reported higher concentrations of total Cr varying between 18.3 and 134.7 μg $L^{-1}$, and classified the Galyan Stream as slightly polluted, based on an annual mean concentration of 47.8 μg $L^{-1}$ by GFAAS.

On the other hand, the allowable concentration for total Cr is 50 μg $L^{-1}$ with reference to national regulation [32] and standard [29], and international directive [34] and guideline [35]. However, it does not match the US EPA [36], which is 100 μg $L^{-1}$ for total Cr (Table 3). Consequently, total Cr concentrations measured throughout the period of study are well below the permissible levels suggested or mandated by these references.

Considering the water-quality reports from March 2015 to February 2016 [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality, it was clearly seen that the treated waters had a high quality with a total Cr concentration of <1 μg $L^{-1}$.

*4.30. Total iron*

Total Fe concentrations were at their lowest values in autumn being 296 μg $L^{-1}$ for Değirmendere and spring being 279 μg $L^{-1}$ for Galyan. Their highest concentrations were in spring being 405 μg $L^{-1}$ for the former and in the winter being

366 μg $L^{-1}$ for the latter. The annual mean values were calculated as 343 and 318 μg $L^{-1}$, respectively, showing a minor difference between these two stations. The waters from the streams are classified as slightly polluted [31] with reference to the upper threshold value of 300 μg $L^{-1}$ for total Fe. Similarly, Bulut et al. [38] classified the Galyan Stream as also slightly polluted, based on the annual mean total Fe concentration of 324 μg $L^{-1}$ by GFAAS.

On the other hand, the RCWIHC [32] and the TS 266 [31] propose the allowable concentration for total Fe as 200 μg $L^{-1}$, which comply with the Council Directive 98/83/EC, however, not with the US EPA, in which the allowable concentration is 300 μg $L^{-1}$ (Table 3). The total Fe concentrations measured throughout the period of study exceeded the permissible levels suggested or mandated by these references [32–35].

Considering the water-quality reports [49] for the drinking water treatment plants of the Trabzon Metropolitan Municipality, it was clearly seen that the treated waters had a high quality with a mean value of 13 μg $L^{-1}$ total Fe, ranging from 2 to 36 μg $L^{-1}$ (Table 5) below these thresholds.

## 5. Conclusions and recommendations

Trabzon Province with a total population of 757,898 is the biggest city on the Southeastern Black Sea Coast. With a main branch length of 55 km and catchment area of 1,054 $km^2$, the Değirmendere Stream watershed receiving untreated domestic wastewater and draining into the Southeastern Black Sea is of prime importance since domestic water demand of Trabzon people is supplied by this watershed.

Based on 1-year observations, it was concluded that the Değirmendere and Galyan streams have high-quality water according to the Turkish Surface Water Quality Regulation in terms of the monitored water-quality indicators. Yet, regarding such indicators as TKN, $o$-$PO_4^{3-}$–P, and total Fe, each stream is classified as slightly polluted. The Değirmendere Stream is also classified as slightly polluted in terms of $NO_2^-$–N.

The surface water quality of the Değirmendere Stream, passing through the city center of Maçka and receiving untreated domestic wastewater, has been ironically degraded. To preserve the water quality, it is recommended that relevant authorities should take the Değirmendere Stream under protection as soon as possible.

Although Değirmendere is untreated wastewater impacted urban stream, it is exceptionally surprising that the Galyan Stream has more concentrations of $NH_4^+$–N with 23%, $NO_3^-$–N with 46%, and TKN with 17% than the Değirmendere Stream has. It has been thought that the more concentrations were due to the chemical fertilizers (e.g., calcium ammonium nitrate and NPK compound fertilizer containing the elements: N, P and K) and animal manure used widely in the Galyan Stream watershed, where hazelnut is intensely cultivated. In order to improve drinking water quality, the fertilizers used for hazelnut cultivation should be limited, and the effectiveness of the fertilizers used should be improved using recent advances. This will further provide reduction of nutrient inputs to the Southeastern Black Sea, which cause coastal eutrophication.

The fact that the Galyan Stream has more TSS of 126% and turbidity of 119% than the Değirmendere Stream has may be misleading since these higher values were due to various construction activities in the Galyan Stream watershed such as dam, soil-saving dams, bridges, levees, sewerage systems, and relocation of roads impacting the water quality temporarily.

Considering the water-quality reports covering a 2-year period from March 2014 to February 2016 for the drinking water treatment plants of the Trabzon Metropolitan Municipality, it was concluded that quality and safety of the treated waters used for drinking purposes were desirable. It was also concluded that the water from the treatment plants should be fluoridated since the Değirmendere and Galyan streams are poor in fluoride regarding the annual mean $F^-$ values of 0.180 and 0.203 mg $L^{-1}$, respectively.

This study continued for one year with monthly monitoring frequency and 30 water-quality indicators due to limited economic and laboratory opportunities. Therefore, a long-term study covering more frequent monitoring and sampling together with more water-quality indicators is strongly recommended to better qualify the quality and safety of the stream waters used for drinking purposes.

Coastal eutrophication has been a serious problem in many coastal waters, especially in land-locked seas. Being one of the largest land-locked seas, the Black Sea has also suffered from this problem. This is a result of nutrients such as nitrogen and phosphorus delivered by the rivers, sewage systems, and so on in increasing amounts to the coastal waters of the Black Sea. Sanitary sewage systems serve 454,306 people in Trabzon Province, and about $23.474 \times 10^6$ $m^3$ of wastewater are generated per year, of which $2.912 \times 10^6$ $m^3$ are discharged by the streams to the Black Sea. Therefore, a specific water monitoring and sampling station should be selected at the Değirmendere Stream mouth to determine the nitrogen and phosphorus export by the stream to the Southeastern Black Sea together with a long-term monitoring.

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