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ORIGINAL ARTICLE

A study on the evaluation of the water quality status for the Büyük Menderes River, Turkey

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Abstract
This study was carried out to assess the water quality of the Büyük Menderes River, as per the criteria of water quality index (WQI) by analyzing 15 physical and chemical parameters in 8 observation stations. The WQI method is considered as one of the most efficient methods of measuring the quality of water. Average WQI values were calculated between 37.27 and 85.96 based on the stations examined, and average values based on months were calculated as 56.88 and 71.38. The highest WQI values at the stations were recorded during April, June, and October. The lowest WQI value was found in the Yenice station and the highest value was recorded at the Sarayköy bridge station. WQI values have varied over a wide range across the entire river. According to WQI scores, statu of river water quality varies between "good" and "very poor". The water quality statu at the stations located at the upstream and downstream of the river route is "good", but at the stations located in the central part of the river, can be classified as "poor" and "very poor". This is mostly due to the aggregation of urban and rural settlements and all commercial activities, which are clustered in the middle part of the river route. Therefore, to prevent pollution of the river and to maintain the water quality, the wastewater originating from domestic sources as well as from industrial activities should be processed and treated before its discharge into the river, and the fertilizers and pesticides utilized in agriculture must be regulated throughout the basin to reduce their exposure to water.

Keywords Water quality index · Pollution · Water pollution · Water quality parameter · Büyük menderes river · Turkey

Based on the WQI evaluation points, the Büyük Menderes river provides valuable information about the general suitability of the water quality status and the locations where pollution is concentrated.

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Introduction

An increase in the population, the growth of economic activities as well as urban expansion cause an increase in water demand. Excessive use of surface water and groundwater endangers a large number of sources due to the decrease in their present amounts and due to the degradation of their quality (Massoud 2012; Sahoo et al. 2015). In the world, rivers are considered as one of the important sources that provide water for a variety of reasons including drinking water, agriculture, ecology as well as the industry. In addition, rivers and their tributaries are used for the discharge of industrial wastewater, sewage, and agricultural drainage waters (Cude 2001a, b). Impairment of surface water quality is turning into a significant problem in various countries across the world (Witek and Jarosiewicz 2009), and as a result, monitoring the quality of water is included as one of the highest priorities in resource conservation policies (Simeonov et al. 2002). Recently, both developed and developing countries have increased their efforts to assess the quality of rivers (Kannel et al.

2007a, b). Due to spatial and temporal changes in water quality, which are often difficult to interpret, it is essential to monitor the composition of the water (Kazi et al. 2009). The determination of the water quality is essential for the optimal allocation of different water sources based on the implementation and use of water conservation policies. Surface waters are generally evaluated using certain norms (Rosemond et al. 2008). Controlling the pollution of rivers caused by non-point sources such as agricultural flow is more difficult as compared to the pollution caused by point sources such as industrial discharges, which necessitates a good monitoring program that will provide timely warnings regarding any changes in the water quality of rivers (Koç 2008). Proper planning and efficient management/operation of water resources require good knowledge and knowhow regarding water quality. These can be obtained through adequate temporal and spatial data collection efforts and then the subsequent analysis and the interpretation of this collected data (Yehia and Sabae 2011). Comparing only the monitoring data on the variables related to water quality without providing a comprehensive assessment of water quality would be insufficient. Currently, the traditional reports of water quality are often very detailed and technical. To address this gap in the assessment of water quality, different Water Quality Indices (WQI: Water Quality Indices) have been formulated to integrate all the relevant water quality variables (Liou et al. 2004). The Water Quality Index (WQI) is one of the methods used to evaluate the water quality of surface water bodies such as rivers. It is widely accepted that WQI can combine various environmental parameters to produce a single dimensionless value, therefore, it offers tools for the rapid assessment and comparison of the water quality of various water systems (Wu et al. 2018). WQI is known to be simple and reproducible (Wu et al. 2018; Abbasi and Abbasi 2012). Various studies have been conducted to evaluate the WQI of water systems that contain living systems such as rivers in various parts of the world (Wu et al. 2018; Lumb et al. 2011; Sutadian et al. 2016). Since WQI aids in understanding the overall water quality status of the water source, it has been widely used in the world for evaluating surface and groundwater quality in recent years (Samantray et al. 2009; Sharma and Kansal 2011; Alam and Pathak 2010; Sebastian and Yamakanamardi 2013; Seth et al. 2014; Tyagi et al. 2013; Bhutiani et al. 2014; VishnuRadhan et al. 2017; Yadav et al. 2015; Dash et al. 2015; Krishnan et al. 2016; Kavıarasan et al. 2016). The primary objective for developing a usable WQI is to take several complex and detailed data sets related to water quality and transforming them into clear and usable information that helps even a non-professional to accurately understand the quality of the water source (Akoteyon et al. 2011; Balan et al. 2012). The objective of WQI is to provide a single value for assessing the water quality of a source by converting the list of parameters and their concentrations (in a water sample) into a single value, which provides a comprehensive analysis and understanding of the water quality. Furthermore, WQI allows the assessment of the suitability of the water to determine if it can be used for different purposes as well (Abbasi 2002). The water quality parameters to be included in the WQI model may vary according to what the water will be used for as well as with local preferences. WQI was created to integrate the various water quality parameters (Cude 2001a, b; Liou et al. 2004; Said et al. 2004). Taking into account the weight of water quality parameters, the WQI method was strongly advocated and used by institutions and institutes that are responsible for controlling the water supplies and water pollution. Various institutions and organizations such as Canadian Council of Ministers' WQI, US National Sanitation Foundation's WQI, British Columbia WQI, Oregon WQI, and Florida Stream WQI have used this parameter to assess the water quality (Debels et al. 2005; Kannel et al. 2007a, b; Abbasi 2002). WQI is also being actively utilized by countries such as Argentina, Brazil, Iran, the USA, Spain, and Malawi (Gor and Shah 2014a, 2014b). Various studies have been conducted to evaluate the WQI of water systems that also contain living systems such as rivers in the various parts of the world (Wu et al. 2018; Lumb et al. 2011; Sutadian et al. 2016). For achieving effective water management, water quality monitoring studies have priority to determine the current conditions and long-term trends. Büyük Menderes river examined in this study meets the water requirements of agriculture, drinking and domestic, industry, tourism and ecological life in the basin. In Büyük Menderes basin, food processing, leather and textile industries, and mining are important activities. There are 14 organized industrial zones in the basin. These sectors operated in the basin create a significant pressure on Büyük Menderes river water quality and the basin. The pollution of river water caused by agricultural, industrial and domestic wastes threatens 2.5 million people living in the basin and their ecological values. Therefore, this study has aimed to evaluate and identify the changes in water quality status and pollution load of the Büyük Menderes basin and river, which is very significant in terms of agriculture, ecology, tourism, drinking water, industrial and utility water; by using WQI thorough the analysis of 15 physical and chemical parameters. Such a study is vital to water resources management, and also strengthens the knowledge base underlying water quality assessment of rivers around the world.

Material and Methods

Material

Study area

Büyük Menderes river is 584 km long. The Büyük Menderes (BM) river basin is located in the west of the Anatolian peninsula. BM basin covers part of the provinces of Afyonkarahisar, Aydın, Burdur, Denizli, Isparta, İzmir, Kütahya, Manisa, Muğla, and Uşak. The area of the basin is 26,361 km^2, which encompasses around 3% of Turkey's land. BM river is the main river basin and the longest river belonging to the Aegean region in Turkey. The river is the most important water body in the basin. The average annual flow volume in the river is about 302×10^9 m^3, and the average annual discharge is 110 m^3/s. The basin has a continental climate in the upstream region, and a Mediterranean climate in the coastal and downstream regions. The average annual temperature of the basin is 17.68 °C and the average annual precipitation is about 642 mm. The river is fed by many tributary rivers such as Banaz, Çürüksu, Çine, Dokuzsele, Dipsiz and Akçay creek. The basin consists of the most agriculturally fertile soil of the country and is heavily dependent on agricultural production. 83% (about 1.6×10^9 m^3) of the river water source is used by irrigation schemes under operation services. Cotton, wheat, corn, alfalfa, sunflower, vegetables, and fruits are the traditional crops of these areas by irrigation tradition. For the utilization of land in the Büyük Menderes River Basin, agricultural use predominates (about 44% of the total basin), then the semi-natural areas (about 33% of the entire basin) take the second place. Approximately 20% of the basin land is covered with forests, and 1% with surface water (DSI 2009; Koç 2008). The population of the basin has reached 2.5 million persons, dispersed mostly in 323 municipalities, where only 179 of them have proper sewerage systems (SIS 2010).

Sampling stations and water quality parameters

To determine the water quality of the Büyük Menderes river in Turkey, the water samples taken from 8 different stations (Adıgüzel dam output, Yenice regulator, Sarayköy bridge, Feslek regulator, Yenipazar bridge, Aydın bridge, Koçarlı bridge, Söke regülatör) located over the river have been analyzed (Fig. 1). These stations were selected primarily to identify critical water quality degradation owing to urban, industrial, agricultural, geothermal pollution. Adıgüzel dam output was called Station 1, Station 2 was Yenice regulator, located at 32 km from the Adıgüzel dam, which suffered pollution from discharges of domestic waste and pesticide into the river. Station 3 was the Sarayköy bridge, which is affected by waste from textile factories, a geothermal plant, and Denizli-Sarayköy sewage. Station 4 was Feslek regulator, where the river is polluted with domestic waste, fertilizers, and pesticide packages. Station 5 was Yenipazar bridge, which is polluted by heavily used fertilizers and pesticide packages. Station 6 was Aydın bridge, which is affected by point sources of pollution, mainly untreated wastewater discharges from industrial zones and municipal sewage treatment plants. Station 7 was Koçarlı bridge, located shortly past the Çine and İkizdere streams, which join the Menderes River. Station 8 was the Söke regulator. Adıgüzel, Yenice and Sarayköy stations are located at the upstream of the river, Feslek and Yenipazar stations at the middle of the river, Aydın, Koçarlı and Söke stations at the downstream of the river. The examined parameters were measured at eight monitoring stations between 2013 and 2018 in February, April, June, August, October, and December. A total of 15 physicochemical parameters (pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Chloride Cl^{-1}), Nitrite-nitrogen (NO_2-N), Ammonium-nitrogen (NH_3–N), Nitrate-nitrogen (NO_3–N), Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Orthophosphates (o–PO_4), Sulphates (SO_4^{-2}), Sodium (Na^{+1}), Potassium (K^{+1}), Calcium (Ca^{+2}), Magnesium (Mg^{+2}). were analyzed and evaluated for the purpose of examining the quality of the Büyük Menderes river by the Quality and Control Laboratory of XXI Regional Directorate. SPSS 17 statistics program was utilized for data analysis. One-way analysis of variance (ANOVA) was applied to the data, and they were subjected to Tukey multiple comparison test. Differences between groups were evaluated at $p < 0.05$. To demonstrate the distribution of data, Box–plot graphs were used.

Methods

Calculating water quality index (WQI)

The selected 15 parameters for this study were evaluated by the Water Quality Index (WQI) method. WQI is a very useful and efficient method for assessing the suitability of water quality, and serves as the basis for water quality assessment in relation to pollution load and water classification of the examined river. There are many parameters that can be tested in a water sample to be examined. However, WQI only reflects the parameters selected. Any index has the potential to miss something when a particular parameter is not included in laboratory analysis. There is no way to be completely objective in the selection process of parameters (Abbasi and Abbasi 2012). WQI has been widely used and applied to data from a number of different geographical areas all over the world to calculate the WQI of various water bodies critical pollution parameters were considered (Abbasi 2002). WQI aims to give a single outcome value to

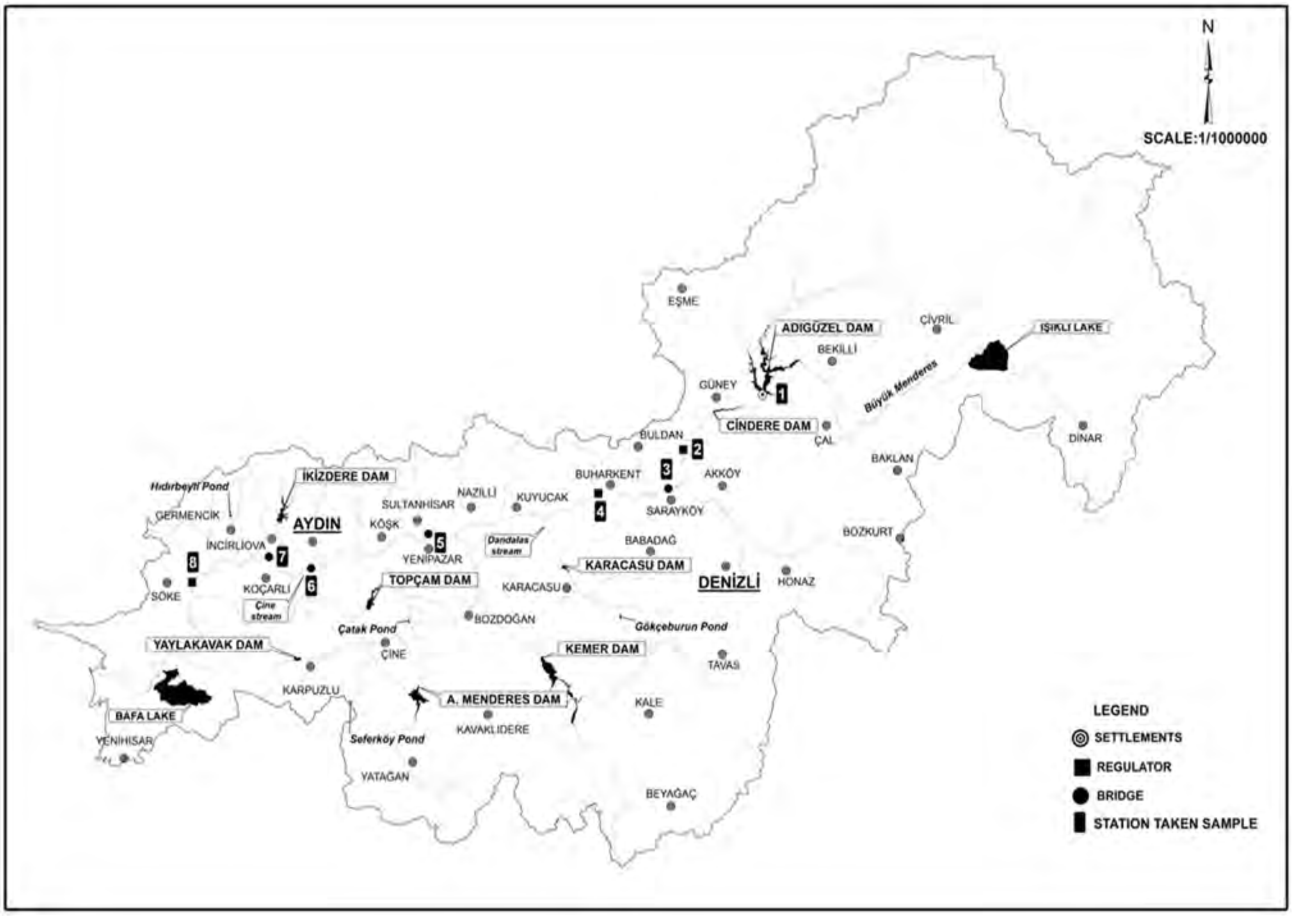


Fig. 1 The stations taken sample from Büyük Menderes river

the water quality of the examined water source by converting the parameters list and their concentrations in a large sample into a single value. WQI, which is a very useful and efficient method, is calculated by using the Weighted Arithmetic Index method as explained by (Cude 2001a, b). According to this method, different water quality parameters are multiplied by a weighting factor determined for each parameter and then summed up using the simple arithmetic mean method. The WQI is calculated as per the quality standards of drinking water recommended by the World Health Organization (WHO). The calculation of WQI is conducted by following the Weight Arithmetic Index method (Cude 2001a, b; Khwakaram et al. 2012), using the equations.

$$Q_i = \left[\left(V_a - V_i\right)/\left(V_s - V_i\right)\right] \times 100 \tag{1}$$

where Q_i the quality rating of ith water quality parameter, V_a actual value of ith water quality parameters, V_i ideal value of water quality parameters [V_i can be obtained from standard tables, $V_i = 0$ except for pH ($V_i = 7$), DO ($V_i = 14.6$ mg/l) (Tripaty and Sahu 2005)], V_s recommended standard permissible value for ith water quality parameter,

$$W_i = k/S_i \tag{2}$$

where W_i unit weight of ith water quality parameter, Q_n is calculated by the equation given below, k proportional constant, and calculated by the equation, $k = [1/\sum 1/S_i = 1,2,3\ldots n]$, $S_i =$ Standard permissible value for ith water quality parameter,

$$\text{WQI} = \sum Q_i W_i / \sum W_i \tag{3}$$

where Q_i the quality rating of ith water quality parameter, W_i unit weight of ith water quality parameter.

Water Quality Status (WQS) determined by Shweta Tyagi et al (2013) as per to the WQI score is presented in Table 1.

Table 1 Possible uses and WQS corresponding to WQI values (Shweta Tyagi et al. 2013)

WQI value	WQS (water quality status)	Grading	Usage possibilities
0–25	Excellent	A	Drinking, irrigation, industrial
26–50	Good	B	Drinking, irrigation, industrial
51–75	Poor	C	Irrigation, industrial
76–100	Very poor	D	Irrigation
Above 100	Unsuitable for drinking	E	Proper treatment is required before use

Results and discussions

The water quality of the Büyük Menderes river

Chemical analysis results of water samples taken between the years of 2013–2018 from 8 stations located in Büyük Menderes River have been provided in Table 2 and the average, standard deviation, minimum and maximum values have been given in Table 3.

pH is one of the most significant parameters providing information about water quality. It affects the physical and biological reactions in the aquatic ecosystem, and the pH level is a measure of the acidity and alkalinity level of a solution (Kılıç 2018; Abdelali et al. 2018). The lowest pH value was recorded at the Adıgüzel dam outlet (7.83 ± 0.27^{b}) and the highest value was recorded at the Sarayköy bridge station (8.10 ± 0.21^{a}) (Fig. 2, Table 2). The difference in the values between the stations was found to be statistically significant ($p < 0.05$). Similar to our study, the highest pH value was found as 8.00 in the study conducted by Küçük (2007) on the Menderes river in 2004. In the study conducted by Yilmaz and Koç (2016a, b), pH values between 2000 and 2013 were found to be lowest (7.79 ± 0.18) at the output of Adıgüzel dam, and the highest (7.99 ± 0.26) at the Söke regulator. Similar pH results were found in the Tigris river (7.8–8.7) (Al-Obaidy Abdul-Hameed et al. 2015). Çürüksu Stream, which joins the Büyük Menderes River near Sarayköy, significantly transports pollution to the river. The biggest reason for the pollution of Çürüksu Stream is Gökpınar Stream, which carries the intense pollution originating from Denizli to Çürüksu Stream. The high Ph value in Sarayköy bridge can be caused by excessive carbonate and bicarbonate ions resulting from agricultural drainage. In addition, it is thought that pollution from domestic and industrial wastewater may cause alkalinity in river water.

Electrical conductivity (EC) is a parameter that shows the ability to conduct current in the water and the total amount of dissolved salt or ions in water (Pal et al. 2015). The salinity of the waters to be used in irrigation or the melted solid content that it contains are expressed as electrical conductivity (Ayyildiz 1976). The lowest electrical conductivity (EC) data value was recorded at Yenice Regulator (721.54 ± 280.96^{c}) and the highest EC value was observed at the Feslek regulator (1774.88 ± 628.67^{a}). (Fig. 2, Table 2). The difference in values between the stations was found to be statistically significant ($p < 0.05$). According to the study conducted by Yilmaz and Koç (2016a, b), the EC values between 2000 and 2013 were found to be the lowest (785.80 ± 135.23) at the exit of Adıgüzel dam, and the highest (1997.39 ± 676.72) at the Feslek regulator. In different studies similar to our study, the EC value was given as (840.3) in the Markanda river, and subsequently, the Meriç river (697), the Tunca river (609), the Ergene river (1925) had respective EC values (Wats et al. 2019; Tokatli 2019). The total concentration of dissolved solids in irrigation waters generally ranges from 150–1500 mg/l.

Total dissolved solid (TDS) is defined as the amount of dissolved material in water and it is also one of the significant water quality parameters. It is utilized continuously to assess the water quality of rivers (Nemati and Naghipour 2014). TDS value was measured lowest at the Yenipazar bridge (383.47 ± 138.88^{d} mg/l) and the highest value was recorded at the Feslek regulator (1286.27 ± 500.22^{a} mg/l). (Fig. 2, Table 2). The difference between the stations was found to be significant ($p < 0.05$). According to the study conducted by Yilmaz and Koç (2016a, b), they found the TDS values between 2000 and 2013 to be lowest (493.25 ± 105.04 mg/l) at the exit of Adıgüzel dam, and the highest (1379.86 ± 502.26 mg/l) at the Feslek regulator. TDS also represent a compound of inorganic ions in natural water from domestic and industrial wastes, that is, from detergent or Chloride, Bicarbonate, Fluoride, Sulfate, and other ions. TDS is strongly related to EC (Hadi et al. 2019). TDS is a measure of water-soluble substances (Kasem et al. 2019). The presence of high amounts of dissolved and suspended solids in water systems, lead to an increase in the need for biological and chemical oxygen, which consume dissolved oxygen levels in aquatic systems. Broadly, it can be stated that TDS levels demonstrate the pollutant load in the water system (Jonnalagadda and Mhere 2001). In different studies similar to our study, the TDS value (198–1200 mg/l) in the Nile delta was determined in the Al-Gharraf River as (620–870 mg/l) and at the Noyyal river as (290–320 mg/l) (Mohamed et al. 2011; Ewaid et al. 2017; Usharani et al. 2010).

Chlorine (Cl^{-}) value was measured lowest at the Adıgüzel dam outlet (47.85 ± 7.64^{a}) and the highest at the Koçarlı bridge station (139.02 ± 403.50^{a}) (Fig. 2, Table 2). It was

Table 2 Results of analyses of water samples taken from the Büyük Menderes River

Stations	pH	EC (µs/cm)	TDS (mg/l)	Cl^- (mg/l)	NO_2-N (mg/l)	NH_4-N (mg/l)	NO_3-N (mg/l)	DO (mg O_2/l)	COD (mg/l)	o-PO4 (mg/l)	SO_4^{2-} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)
Adıgüzel	7.83 ± 0.27^{b}	771.91 ± 114.13^{e}	458.19 ± 73.44^{e}	47.85 ± 7.64^{a}	0.08 ± 0.14^{a}	0.25 ± 0.25^{a}	1.15 ± 0.59^{c}	6.12 ± 2.13^{cd}	9.74 ± 5.88^{c}	0.10 ± 0.09^{b}	97.13 ± 17.84^{d}	48.16 ± 9.45^{ef}	6.20 ± 1.28^{b}	64.19 ± 10.38^{cd}	30.63 ± 3.69^{d}
Yenice	8.04 ± 0.31^{a}	721.54 ± 280.96^{e}	537.58 ± 200.11^{de}	50.43 ± 21.28^{a}	0.04 ± 0.14^{a}	0.66 ± 1.95^{a}	1.44 ± 1.27^{bc}	9.62 ± 1.70^{a}	10.63 ± 9.44^{c}	1.66 ± 9.60^{b}	314.94 ± 135.84^{d}	56.57 ± 28.59^{def}	8.31 ± 6.97^{ab}	99.44 ± 37.58^{b}	33.16 ± 9.66^{d}
Sarayköy	8.10 ± 0.21^{a}	1629.41 ± 611.53^{ab}	1218.97 ± 538.42^{ab}	134.76 ± 65.41^{a}	0.36 ± 0.81^{a}	0.68 ± 1.05^{a}	2.31 ± 1.79^{ab}	6.79 ± 1.75^{bcd}	25.13 ± 14.36^{b}	0.40 ± 0.31^{b}	462.30 ± 245.62^{a}	125.44 ± 55.06^{ab}	7.49 ± 2.83^{ab}	134.11 ± 49.83^{a}	78.46 ± 33.36^{a}
Feslek	8.01 ± 0.12^{a}	1774.88 ± 628.67^{a}	1286.27 ± 500.22^{a}	123.94 ± 61.84^{a}	0.14 ± 0.24^{a}	0.71 ± 1.05^{a}	2.60 ± 1.56^{a}	5.56 ± 1.21^{d}	14.60 ± 10.52^{c}	0.37 ± 0.30^{b}	229.19 ± 137.45^{a}	131.47 ± 59.71^{a}	9.61 ± 3.31^{a}	133.08 ± 44.72^{a}	84.84 ± 39.33^{a}
Yenipazar	8.06 ± 0.18^{a}	948.86 ± 205.45^{de}	383.47 ± 138.88^{d}	53.15 ± 17.14^{a}	0.04 ± 0.00^{a}	0.03 ± 0.02^{a}	2.24 ± 0.54^{ab}	8.8 ± 2.94^{a}	35.27 ± 17.26^{a}	0.01 ± 0.00^{b}	432.09 ± 185.27^{cd}	27.83 ± 5.98^{f}	7.01 ± 0.00^{b}	61.02 ± 28.15^{d}	48.10 ± 20.27^{cd}
Aydın	8.04 ± 0.12^{a}	1360.19 ± 447.49^{bc}	981.22 ± 443.5^{bc}	87.17 ± 44.21^{a}	0.17 ± 0.66^{a}	0.44 ± 0.92^{a}	1.88 ± 0.99^{abc}	6.79 ± 0.96^{bcd}	9.60 ± 3.64^{c}	0.81 ± 1.34^{b}	223.66 ± 123.65^{b}	96.72 ± 45.83^{bc}	8.29 ± 3.12^{ab}	99.44 ± 37.58^{b}	77.00 ± 25.39^{ab}
Koçarlı	8.04 ± 0.14^{a}	1120.83 ± 488.64^{cd}	763.80 ± 382.85^{cd}	139.02 ± 403.50^{a}	0.39 ± 1.24^{a}	0.49 ± 0.76^{a}	2.56 ± 1.87^{a}	7.11 ± 1.34^{bc}	14.42 ± 8.02^{c}	7.72 ± 17.59^{a}	104.16 ± 55.95^{ab}	72.66 ± 46.95^{cde}	7.11 ± 3.52^{b}	86.37 ± 36.63^{bc}	57.17 ± 27.55^{e}
Söke	8.09 ± 0.16^{a}	938.61 ± 588.17^{de}	753.90 ± 366.25^{cd}	82.87 ± 48.36^{a}	0.13 ± 0.26^{a}	0.36 ± 0.39^{a}	2.36 ± 1.64^{a}	7.47 ± 1.57^{b}	13.73 ± 6.96^{c}	0.83 ± 3.02^{b}	183.95 ± 86.22^{ab}	83.35 ± 41.62^{de}	7.69 ± 3.12^{ab}	81.26 ± 31.62^{bc}	59.04 ± 24.22^{bc}

Values (mean ± SEM, n=3) with different superscript letters in the same line are significantly different between groups ($p < 0.05$)

Table 3 Result of samples statistical parameters computed using the chemical data

Stations	pH	EC (µs/cm)	TDS (mg/l)	Cl^- (mg/l)	NO_2-N (mg/l)	NH_4-N (mg/l)	NO_3-N (mg/l)	DO (mg O_2/l)	COD (mg/l)	o-PO4 (mg/l)	SO_4^{2-} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)
n	288	288	288	288	288	288	288	288	288	288	288	288	288	288	288
Mean	8.03	1150.78	797.92	89.90	0.17	0.45	2.07	7.28	16.64	1.49	255.92	80.27	7.71	92.58	58.55
Std. deviation	0.21	589.18	482.97	150.86	0.60	0.99	1.44	2.17	13.30	7.49	189.43	53.17	3.64	43.06	31.65
Minimum	7	6.35	0.00	0.23	0.00	0.00	0.03	1.70	0.04	0.00	8.56	1.30	1.15	21.00	2.10
Maximum	8.80	3470.00	2840	2478	6.40	9	8.13	14	69	57.69	1061.50	322	37	220.40	214.00

determined that the difference between the stations was not significant ($p > 0.05$). Similarly, in the study conducted by Yılmaz and Koç (Yilmaz and Koç 2016a, b), it was detected lowest at the Adıgüzel dam outlet (50.81 ± 16.45), and highest at the Sarayköy bridge location (160.14 ± 60.24 mg/l). In irrigation waters, chlorides are known as the most problematic anions. It has been suggested that the chloride concentration in the Ohio river should not exceed 125 mg/l per month. This value is stated as an average value. It was recommended that the maximum value should not exceed 250 mg/l. The reason for this recommendation is economic-based rather than public health concerns. In terms of health, if the chloride concentration is less than 125 mg/l, it is acceptable, if it is between 125 and 250 mg/l, it is considered as suspicious and if it is more than 250 mg/l, it is considered as unsuitable (Ayyıldız 1976). In different studies similar to our study, the Cl^- value was determined at Hindon river as (201–1326 mg/l), at Cauvery river as (176–254 mg/l) and at Narmada river as (30.5–209.79 mg/l) (Suthar et al. 2009; Abida and Abida 2008; Sharma et al. 2008).

Nitrite Nitrogen (NO_2–N) value was measured lowest at the Yenipazar bridge (0.04 ± 0.00^a) and the highest at the Koçarlı bridge station (0.39 ± 1.24^a). (Fig. 2, Table 2). It was determined that the difference between the stations was not significant ($p > 0.05$). Similarly, in the study conducted by Yilmaz and Koç (2016a, b), it was detected lowest at the Adıgüzel dam outlet (0.02 ± 0.00^g), and the highest at Sarayköy bridge (0.13 ± 0.10^a mg/l. In different studies similar to our study, NO_2–N value was determined at Tunca river as (0.00–0.12 mg/l), at Drava river as (0.001–0.140 mg/l) and at Pearl river (as 0.001–0.156 mg/l) (Camur-Elipeka et al. 2006; Gvozdic et al. 2012; Ouyang et al. 2006).

Ammonium nitrogen (NH_4-N) value was measured lowest at the Yenipazar bridge (0.03 ± 0.02^a) and the highest at Feslek regulator (0.71 ± 1.05^a). (Fig. 2, Table 2). It was determined that the difference between the stations was not significant ($p > 0.05$). In another study similar to our study, the NH_4-N value was determined at the Dagang river as (0.58 mg/L), in the Taipu river as (0.23 mg/L), and in Xu river as (0.72 mg/L) (Xiao-long et al. 2007). Since there is agricultural land around the Menderes river, the use of nitrated fertilizer is high here, hence the nitrate-nitrogen concentration value is also found to be high in the Feslek regulator. At this point, there is also a lack of dissolved oxygen due to the oxidation of organic matter. This situation increases the amount of ammonium nitrogen in the Feslek regulator. The presence of ammonium salts in irrigation waters has an effect of increasing dispersion in soil while lowering permeability in a discontinuous manner (Kalıpçı et al. 2017).

Nitrate Nitrogen (NO_3–N) value was measured lowest at the Adıgüzel dam outlet (1.15 ± 0.59^c) and the highest at the Feslek regulator (2.60 ± 1.56^a). (Fig. 2, Table 2). The

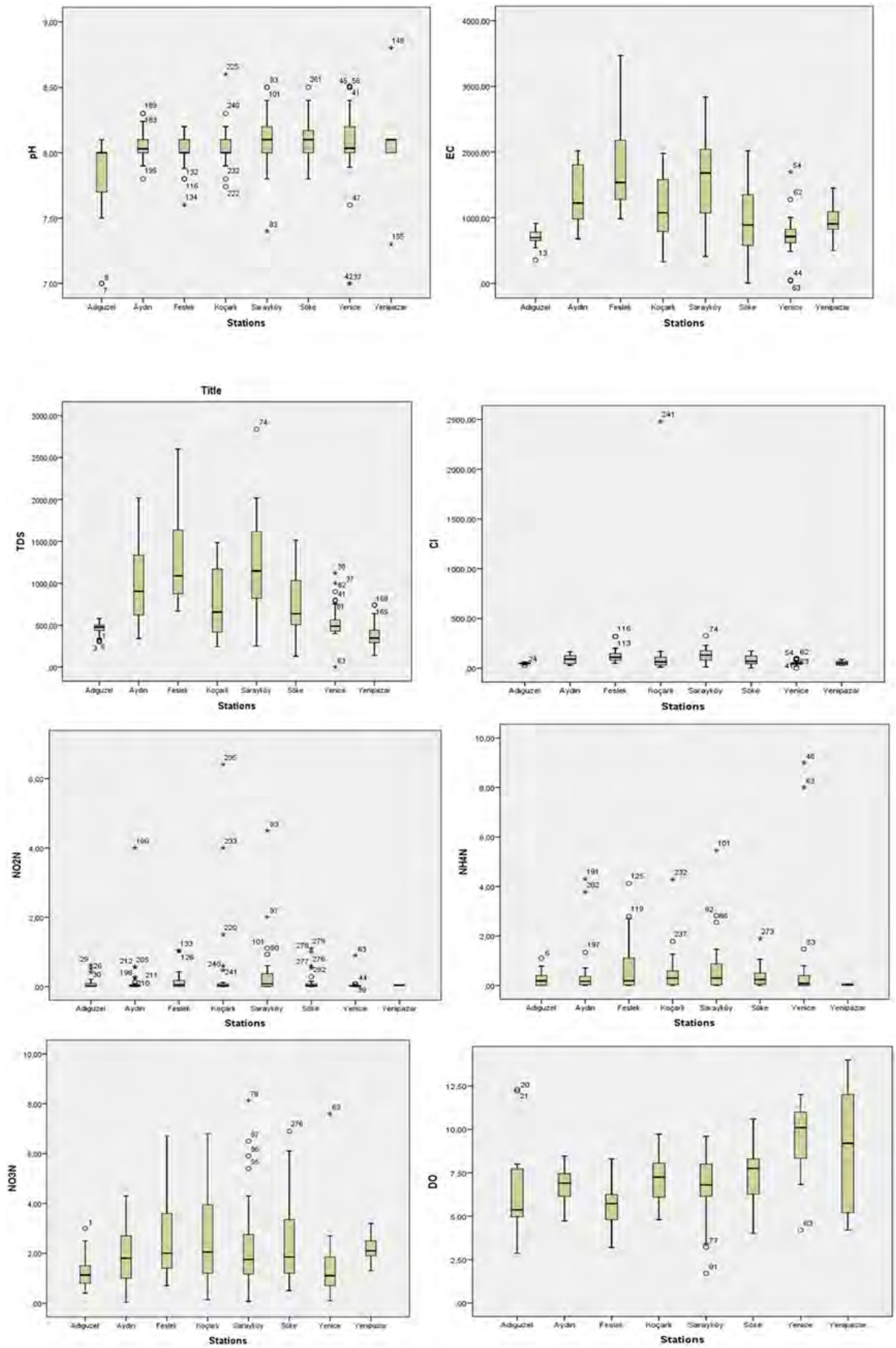


Fig. 2 Change graphics of pH, EC, TDS, Cl^{-1}, NO_2N, NH_4N, NO_3N, DO values in the Büyük Menderes River

difference between the stations was found to be significant ($p < 0.05$). Similarly, in the study conducted by Yilmaz and Koç (2016a, b), it was detected lowest at the Adıgüzel dam exit (0.81 ± 0.60), the highest at the Sarayköy bridge station (2.44 ± 1.14 mg/l). In the study by Koç (2010), the amount of nitrate in the upstream of the Büyük menderes river was found to be 2.5 mg/l. In a different study, it was seen that the NO_3-N value varies widely in the Warta river (0–18 mg/l) (Górski et al. 2019). It is thought that NO_3-N concentration on the Sarayköy bridge is caused by excessive fertilizers mixed with water and factory wastes from factories that produce chemical fertilizers.

Dissolved oxygen (DO) identifies biological changes created by aerobic or anaerobic organisms. Therefore, measurement of DO is important for maintaining aerobic treatment processes aimed at purifying domestic and industrial wastewater. The optimum value of DO for healthy aquatic life and good water quality is 4–6 mg/l (Alam et al. 2007; Avvannavar and Shrihari 2008). DO value was measured lowest at the Feslek regulator (5.56 ± 1.21^{d}) and the highest at the Yenice regulator (9.62 ± 1.70^{a}). (Fig. 2, Table 2). The difference between the stations was found to be significant ($p < 0.05$). Excessive DO is actually a desired condition for the natural treatment of surface waters and for life present in water. For this reason, the fact that it is high in the Yenice regulator should be considered as a positive situation.

Chemical oxygen demand (COD) is an important index of organic pollution in the river. COD value was measured lowest at the Aydın bridge (9.60 ± 3.64^{c}) and the highest at Yenipazar bridge (35.27 ± 17.26^{a}). (Fig. 3, Table 2). The difference between the stations was found to be significant ($p < 0.05$). Similarly, in the study conducted by Yılmaz and Koç (2016), it was detected lowest at the Adıgüzel dam output (16.35 ± 13.30), the highest at the Sarayköy bridge (44.47 ± 28.94 mg/l). In the study conducted by Küçük (2007), the COD value was found between 20–126.7 mg/l. Low chemical oxygen demand in Aydın bridge means that organic pollution is low. In a different study, the COD value was determined to be 0.8–2.80 mg/L in the Mahi river (Gor and Shah 2014a, b). High COD values can be caused by the leaching of chemically degradable organic and inorganic waste matter originating from the surrounding regions which are intensely populated. In India, Chounhary et al. (2011) in their study reported about three dams that are polluted to some extent; but in the study, it was especially highlighted that the Kerwa dam is the most polluted dam as indicated by a very high value of COD. The primary pollution sources for Kerwa dam originate from the settlement around the dam as well as the daily activities of these settlements. In a study, conducted by Şener et al. 2017), it was demonstrated that an increase in the COD values in the Aksu River, Turkey is caused by agricultural and industrial activities in the region. When we look at the parameter value of COD from the industrial pollution load coming into the basin, it is mostly seen at Yenipazar station. 59% of the COD pollution load coming to the basin comes from domestic sources (Koç 2015).

Phosphate (o-PO_4) was measured lowest at the Adıgüzel dam outlet (0.10 ± 0.09^{b}) and highest at the Koçarlı bridge (7.72 ± 17.59^{a}) (Fig. 3, Table 2). The difference between the stations was found to be significant ($p < 0.05$). Similarly, in the study conducted by Yılmaz and Koç (2016), it was detected lowest at the Adıgüzel dam outlet (0.23 ± 0.09), and the highest at the Söke regulator which is near the Koçarlı bridge (0.42 ± 0.27 mg/l). Pollution in agricultural and residential areas around the Koçarlı bridge causes an increase in phosphate levels. The total phosphorus (P) which occur the non-point pollution load in the basin come from Denizli, Aydın and Uşak provinces, respectively. It is observed that the non-point pollution load is mostly caused by agricultural areas since there is intensive agricultural activity in the basin. It was determined that 64% of the total P load came from point sources and 36% from non-point sources. (DSİ 2016).

Sulfate (SO_4^{-2}) was measured lowest at the Adıgüzel dam outlet (97.13 ± 17.84^{d}) and highest at the Sarayköy bridge station (462.30 ± 245.62^{a}). (Fig. 3, Table 2). It was determined that the difference between the stations is important ($p < 0.05$). In the study conducted by Yilmaz and Koç (2016a, b), the lowest value was recorded in the Yenice bridge station (108.38 ± 100.47), and the highest value in the Feslek regulator (580.81 ± 245.04 mg/l). The reason for the high concentration of sulfate in the Sarayköy Bridge can be attributed to the density of industrial activities and the feeding of approximately 57% of the Büyük Menderes River with the water coming from the Çürüksu Stream.

Sodium (Na^{+}) was measured lowest at the Yenipazar bridge (27.83 ± 5.98^{f}) and highest at the Feslek regulator (131.47 ± 59.71^{a}) (Fig. 3, Table 2). The difference between the stations was found to be significant ($p < 0.05$). Soil saturated with sodium shows an oily appearance. Colitis of Sodium soil causes swelling, clogs the soil pores, reduces the air and water permeability of the soil, and raises the pH of the soil solution to harmful levels. In the study conducted by Yılmaz and Koç (2016), the lowest value was detected in the Yenice bridge station (75.26 ± 36.50), and the highest value was recorded in the Feslek regulator (153.30 ± 73.76 mg/l). In another study, the value of Na was determined at Kosi River as (8.4–8.8 mg/l), at Cauvery river as (6.8–40 mg/l) and at Asi river as (7.82–126.96 mg/l) (Bhandari and Naya 2008; Begum and Harıkrıshna 2008; Kılıc and Yücel 2018).

Potassium (K^{+}) was measured lowest at the Adıgüzel dam outlet (6.20 ± 1.28^{b}) and the highest at the Feslek regulator (9.61 ± 3.31^{a}) (Fig. 3, Table 2). The difference between the stations was found to be significant ($p < 0.05$). In the study conducted by Yilmaz and Koç (2016a, b), it was detected

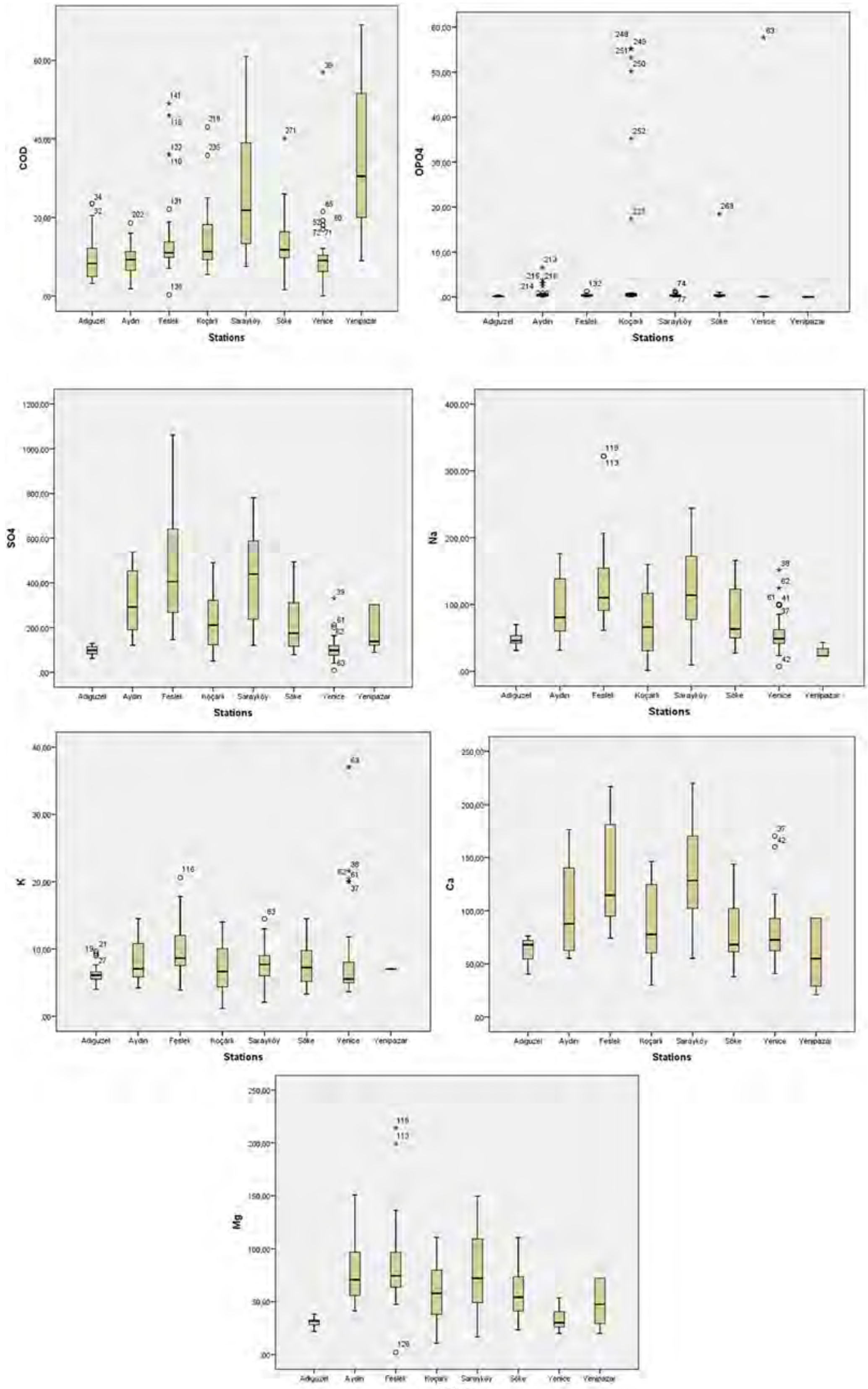


Fig. 3 Change graphics of COD, O-PO_4, SO_4, Na, K, Ca, Mg values in the Büyük Menderes River

lowest at the Adıgüzel dam outlet (6.20 ± 1.27), and highest at the Feslek regulator (10.85 ± 3.77 mg/l). In different studies, the K^+ value was found to be (0.08–0.19 mg/l) in the Ossah river and as (1–5 mg/l) in the Nambol river (Donald and Blesssing 2019; Devi et al. 2015). Potassium is the fourth naturally occurring cation in the freshwater ecosystem and it is always found in lesser amounts than sodium, calcium, and magnesium (Siddiqui 2007).

Calcium (Ca^{+2}) was measured lowest at the Yenipazar bridge (61.02 ± 28.15[d]) and the highest at the Sarayköy bridge (134.11 ± 49.83[a]) (Fig. 3, Table 2). The difference between the stations was found to be significant ($p < 0.05$). In the study conducted by Yilmaz and Koç (2016a, b), it was detected lowest at the Adıgüzel dam exit (75.90 ± 25.24), and the highest at the Sarayköy bridge (149.02 ± 51.90 mg/l). In different studies, Ca^{2+} value was determined as (2.10–2.73 mg/l) in Taylar stream, it was determined in Nigerian river as (1.37–2.62 mg/l), in Coruh river as (63.75–76.24 mg/l) and in Nambol river as (5.6–12.8 mg/l) (Aigberua and Tarawou 2019; Donald and Blessing 2019; Birici et al. 2017; Devi et al. 2015). In their study, Küçük (2007) determined the calcium value in the Menderes river as 53–174 mg/l.

Magnesium (Mg^{+2}) was measured lowest at the Adıgüzel dam outlet (30.63 ± 3.69[d]) and highest at the Feslek regulator (84.84 ± 39.33[a]) (Fig. 3, Table 2). The difference between the stations was found to be significant ($p < 0.05$). Similar to our study, in the study conducted by Yilmaz and Koç (2016a, b), it was detected lowest at the Adıgüzel dam outlet (38.65 ± 9.59) and the highest at the Feslek regulator (109.87 ± 45.58 mg/l). In different studies, Mg^{2+} value of (0.58–1.07 mg/l) was found in Taylar stream, in Nyando river as (0.02–0.25 mg/l) and in Köprüçay river as (23.28–1275.75 mg/l) (Aigberua, and Tarawou 2019; Achieng et al. 2019; Erdoğan and Ertan 2016). Küçük (2007) determined the magnesium value in the Büyük Menderes river to be between 26.7 and 116.7 mg/l.

WQI analysis for the Büyük Menderes river

The first step in the WQI method is to calculate the weight value determined for each chosen physical and chemical parameter. Water samples taken from 8 stations determined on the Büyük Menderes river were analyzed as per 15 main physical and chemical parameters. WQI values of 8 stations determined from the upstream to the downstream of the river were calculated and water quality analyzes were examined. The WQI values at the stations, based on the months from which water samples were taken, are presented in Fig. 4, and the WQI values calculated by months on the basis of the stations are presented in Fig. 5. Average WQI values vary between 37.27 and 85.96 on a monthly basis at the stations. The highest WQI values were realized in Sarayköy, Feslek, and Yenipazar bridges. The highest WQI value was calculated at the Sarayköy bridge station in April with 101.27. In addition, the Koçarlı bridge has a partly High WQI value. According to the calculated WQI values, the water quality status in these stations is between "good" and "very poor" quality limits. For this reason, the current water supply is within the usable limit for only irrigation. The highest WQI values were calculated in April, June, and October. Considering the average WQI values in the years examined in Fig. 6, the highest WQI values were realized in Sarayköy, Feslek, Yenipazar, and Koçarlı bridges. In the 8 stations examined, the lowest WQI score was in the Yenice regulator (37.27) and the highest score was in Sarayköy bridge (85.96). The pollution is concentrated in the central part of the Menderes basin. WQI scores varied over a wide range along the entire river route. According to the average monthly values in the years examined for each station, at the exit of Adıgüzel, WQI value is 40.66 (good), Yenice regulator 37.27 (good), Sarayköy bridge 85.96 (very poor), Fezlek regulator 70.78 (poor), Yenipazar bridge 83.62 (very poor), Aydın bridge 50.74 (poor), Koçarlı bridge 74.21 (poor), and finally, the WQI value for the Söke regulator is 55.74 (poor). In the years studied, WQI values at Adıgüzel station were between 30.05 and 42.60, Yenice bridge 30.79–49.35, Sarayköy bridge 69.31–101.27, Feslek regulator 64.36–86.69, Yenipazar bridge 72.92–92.94, Aydın bridge 41.45 and 67.13, Koçarlı bridge 64.89 and 79.87, Söke regulator was between 48.30 and 65.05. Average WQI values by stations in the studied years are presented in Fig. 7. Considering the WQI values given in the Fig. 7 for the years examined, Sarayköy, Feslek, Yenipazar, and Koçarlı bridges are within the "poor and very poor" water quality status. 87% of the existing water source in the Büyük Menderes river is used for irrigation. In this context, the existing water supply in the river can only be used for irrigation purposes. WQI scores were also high, since the weight values related to COD, DO, NH_4-N, and K parameters were high. In particular, the high flowing water released from the dams to the riverbed in August reduces the pollution concentration, as the high flow rates formed in the riverbed, due to the increase in rains in October and December, decrease pollution concentrations, and hence the WQI values decrease accordingly. Especially in April and June, pollution concentrations increase and thus WQI values increase due to the low rainfall and due to the stoppage of water release for irrigation from the dams to the riverbed. In the winter season, the riverbed flow rate is lower compared to the main bed flow rate, so the point pollution flow rates are more effective in winter than the irrigation period. The water quality status of the Büyük Menderes river is in the range of "good" and "very poor" according to the calculated WQI values, considering the stations and years examined. The water quality status in the upstream and downstream

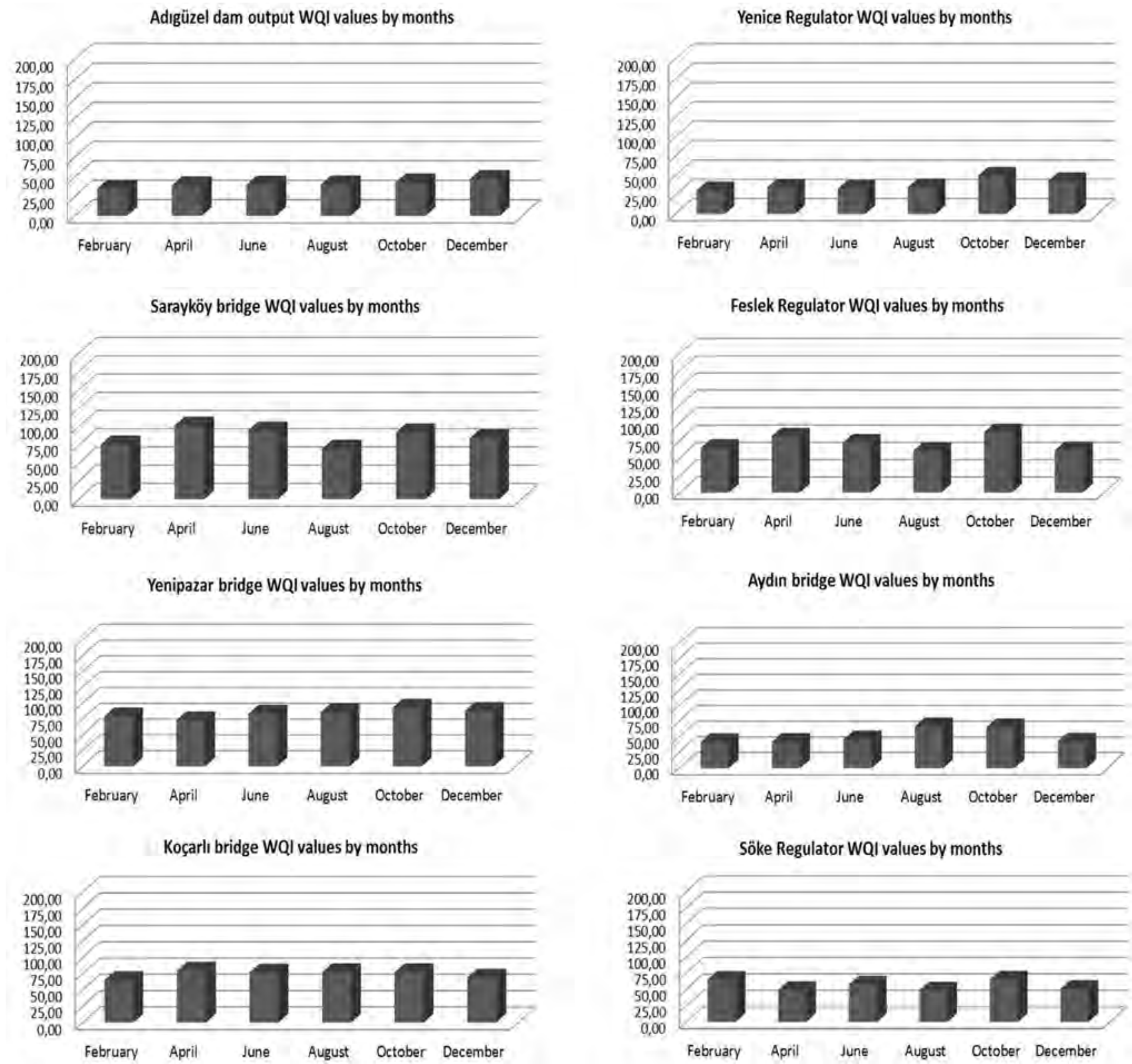


Fig. 4 WQI values in stations as per the months

regions of the basin is in the "good", however, the water quality status in the central part of the river is in the "poor" and "very poor". This is due to the concentration of urban and rural settlements in the middle part of the riverbed route and the gathering of all commercial activities in this region. The waters in this category can only be used for irrigation. The source of pollution in Sarayköy, Yenipazar, and Koçarlı bridges are wastewater from industrial facilities, intensive agricultural activities, and settlements in the region. In the Feslek regulator, it is caused by geothermal power plants and intensive agricultural activities and settlements (Koç 2007). In addition, the Büyük Menderes river passes right in the middle of the basin and intense urban and rural settlements have been developed on both sides of the river, and industrial facilities have also subsequently increased. In this context, demographic and socioeconomic pressures on the river and basin are increasing. The high WQI scores observed in the river basin are primarily due to various anthropogenic activities such as direct wastewater and sewage inflow from residential and commercial establishments in the region, lack of proper sanitation systems, wastes from agricultural activities, direct release of untreated wastewater from small and large-scale industries and factories to the riverbed. The major point source pollutants which threaten

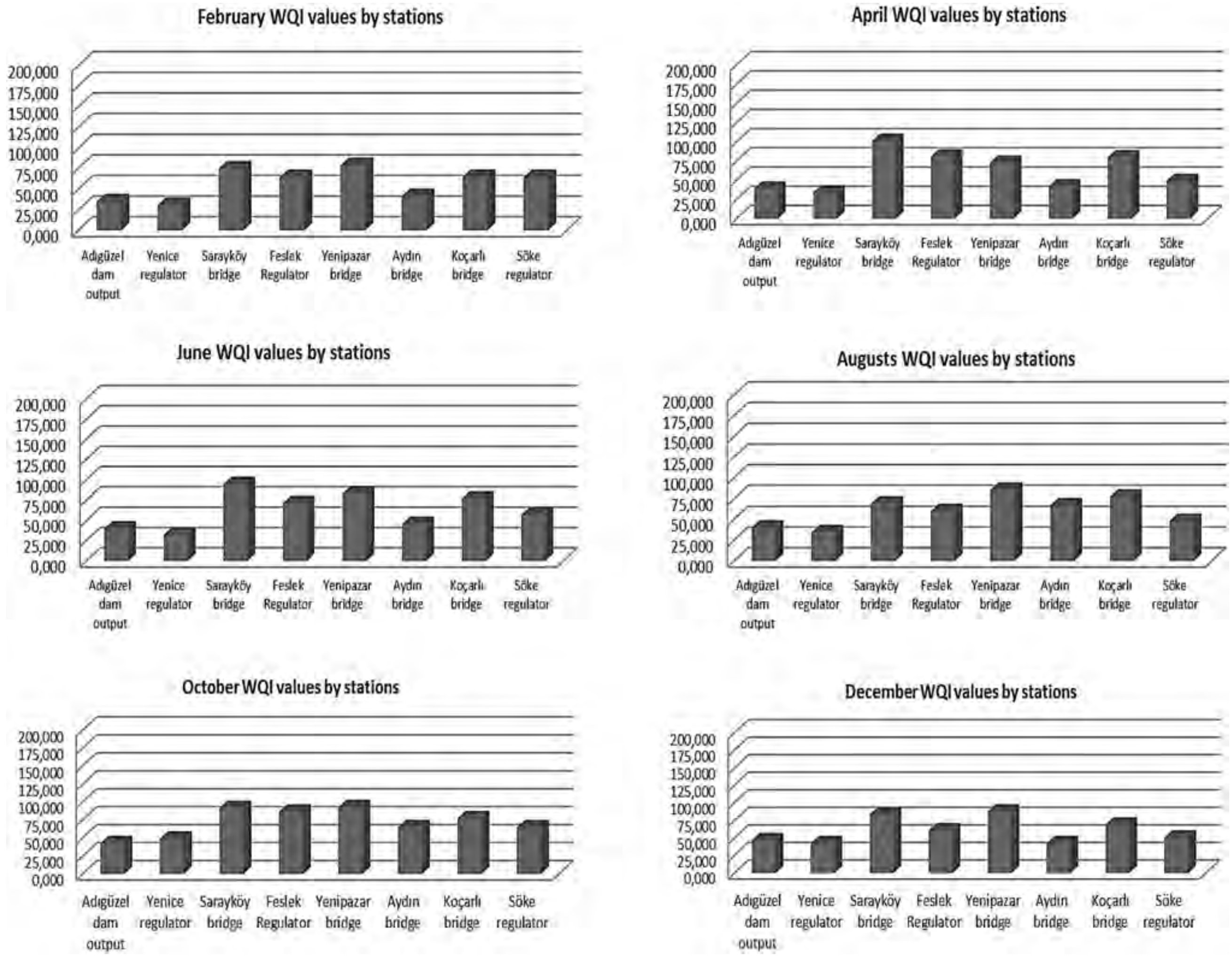
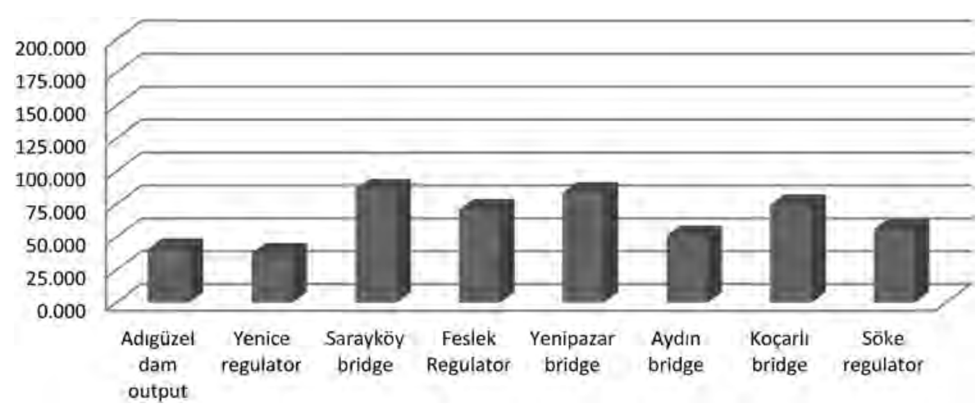


Fig. 5 WQI values as per the months in stations

Fig. 6 Average WQI values at stations



the Büyük Menderes Basin can be grouped as domestic and industrial wastewater, leakage, olive black-water and geothermal waters. The main industrial sectors that can create a pollution load within the Büyük Menderes Basin are textile, leather and olive oil production. Textile fabricates operating in the basin are concentrated in Denizli and Uşak provinces. Although most of the fabricates have Wastewater Treatment Plants (WWTP), many fabricates do not operate their WWTPs and leave their wastewater to the Büyük Menderes river. As of today, the pollution situation in Büyük Menderes

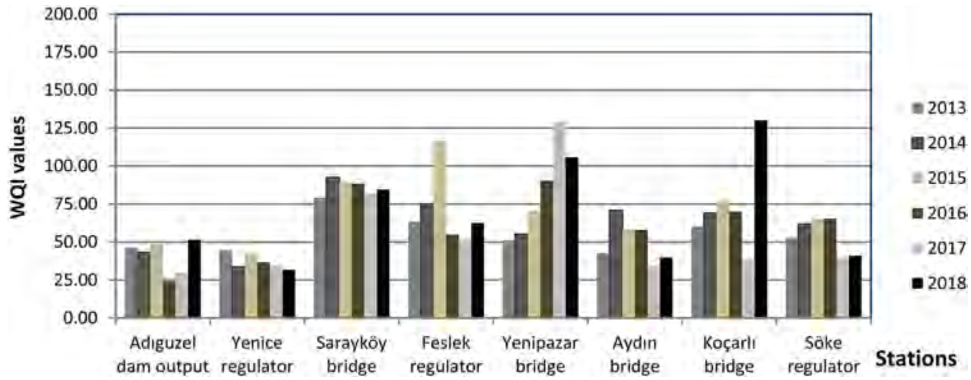


Fig. 7 Average WQI values by stations in the years studied

basin is not sustainable. Büyük Menderes Basin pollution prevention program should be prepared immediately, and implemented. Rather than establishing the necessary measures program to ensure the environmental objectives of the measures to be taken, it is the effective implementation of this created program. Therefore, issues such as the base, applicability and acceptance by the implementers of the program should be taken into account while creating the measures program.

Conclusion

The WQI method is an effective method used to evaluate and manage water quality. Based on the WQI evaluation points, the Büyük Menderes river provides valuable information about the general suitability of the water quality statu and the locations where pollution is concentrated. It emphasizes the distinctive features of physical and chemical parameters of various importance that affect the overall water quality of the river. The change of WQI values in the basin was examined on a monthly basis and within the context of examined station points. The basic data obtained in this study, their analysis and interpretation, and the determination of the factors affecting the Büyük Menderes river will help us develop our knowledge base on the status of the water quality of a socioeconomically vital system.

This work carried out has importance both academically and practically. Based on the observed WQI assessment results, it can be concluded that effective and efficient water treatment measures are urgently required to improve the river water quality by defining an appropriate water quality management plan to support a future plan for sustainable river restoration.

More work should be done to further illuminate this important river which feeds the basin in terms of agriculture, industry, tourism, ecology and drinking water. Some parameters should be added to cover as possible as the current situation of Büyük Menderes River. A strategic plan should be prepared to define how to protect the environment and how to inform local people about this pollution produced.

Taking measures including preventing raw sewage flows from residential and commercial areas, limiting direct drainage of rainwater drains into the river, and preventing solid waste discharge by communities living alongside the river will significantly improve the water quality of the river.

The population is increasing rapidly every year due to migrations in the basin. The infrastructure needs of the growing population must be met regularly. There is an increase in the amount of domestic waste with the increase in population. To prevent this, separate systems should be established with one system for the drainage of sewage and treatment plants and a separate system for the drainage of rainwater. Furthermore, the regular operation of sewage treatment plants should be enforced.

To protect and improve water quality, the textile industry, leather industry, organized and individual industry factories, olive oil, and similar enterprises operating in the same field of work, as well as geothermal power plants, are required to discharge their wastewater into the river after treatment. The olive oil production facilities function as both point pollution source and a diffuse pollution source. Some olive oil production facilities treat wastewater, and the effluent water becomes a source of point pollution. Some facilities accumulate their wastewater in pools. These pools overflow with excessive rainfall, so these facilities cause diffuse pollution.

To achieve the expected benefits from fertilizing in the basin agricultural areas, the type and the amount of fertilizer to be applied should be determined according to the nutrient needs of the plant to be grown as well as by the soil and climate characteristics, and then the farmers should be informed about the type, amount, time and the best methods for applying the fertilizer. In this manner, the use of excessive and untimely fertilizers should be prevented, and the transport of nitrogen and phosphate to the riverbed should be minimized by surface and underground flows.

To ensure sustainable natural resource management in the basin and to improve the river water quality, integrated river basin management should be initiated (Koç 2015). In addition, integrated watershed management plans for the basin should be prepared, the legal infrastructure should be established, and it must be ensured that water users participate in watershed water management.

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