International Journal of Environmental Science and Technology (2022) 19:4069–4086
https://doi.org/10.1007/s13762-021-03886-y

ORIGINAL PAPER

Impacts of construction of dam on the flow regimes and water quality: a case study from Turkey

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Received: 7 June 2021 / Revised: 9 November 2021 / Accepted: 26 December 2021 / Published online: 1 February 2022

Abstract

Dam construction has important positive and negative effects on the environment, including physical changes of the riverbed morphology, changes in sediment transport patterns and water quality, and the river ecosystem in general. The primary objective of this study is to present a methodology to assess the impacts of construction and operation of Çine Dam, in Aydin, Turkey, on the river flow regimes, sedimentation, and water quality of the downstream reach of Büyük Menderes River. Construction of the dam significantly reduced the sediment load from the Çine tributary to the main reach, as expected. To evaluate changes in the water quality of the Çine River, five different water quality index methods are compared before and after the dam operation: Weighted Arithmetic Index (WAI-WQI), Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI), Universal Water Quality Index (UWQI), Oregon Water Quality Index (OWQI) and Aquatic Toxicity Index (ATI). ATI and CCME-WQI methods are found to be more appropriate for the 10-year water quality assessment of the river.

Keywords Çine dam · Reservoir · Impacts of dams · Water quality · Water quality index · Flow regime · Sedimentation

Introduction

Large dams are constructed around the world for the multiple purposes, including flood control, water supply, hydroelectric power generation, navigation, and recreation. Dam construction has important positive and negative effects on the environment. While contributing to meeting the increasing water and energy demands of countries, it also affects the river ecosystem by altering aquatic ecology and river hydrology upstream and downstream, and by affecting water quality and quantity, producing an artificial aquatic environment for the life ecosystem. When a new dam reservoir is constructed, the upper reaches of the reservoir may not be affected as the original riverine conditions are still retained; however, both the quantity and the quality of the water are seriously affected in downstream areas. The dam acts as a barrier between the upstream and downstream habitat of migratory fish. Also, native fish in the river system can also be greatly affected by the changes in their natural habitat because reservoirs convert well-mixed waters of flowing rivers to thermally stratified lakes. Fish can also be killed in reservoirs as they are pulled into the intake. The impacts of dams also include physical changes of river and floodplain hydrology, sediment movement and channel structure. They change the riverbed morphology, which causes scouring, especially in the downstream, and negatively affects the shape of the natural riverbed (Dai et al. 2008; Latrubesse et al. 2017). Also, sediment particles in water might behave as a carrier for heavy metals which have affinity to attach to cohesive sediments. They serve as a major pollutant and can cause disruption of ecosystems (Bor 2008). Sediment particles such as nitrogen, organic compounds, residues, pathogenic bacteria, pesticides, and viruses are carried into reservoirs, deteriorate water quality, and cause a range of illness (WMO, 2003).

Especially in areas of intense agricultural activity, soils rich in organic matter and saturated with water increase the

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Editorial responsibility: SHussain.

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variety and productivity of agricultural products. However, a dam built on the stream disrupts the transport of organic matter and affects the chemical and biological properties of the natural river ecosystem. Certain elements have a greater tendency to accumulate in stagnant water within the reservoir (Gwiazda and Boron 2002). All elements of the hydrological cycle and natural resources are disrupted by population growth leading to increased migration from rural areas to cities. In combination with the pollution from agricultural, domestic, and industrial sources, with the unfavorable changes in precipitation regimes due to global climate change, clean reliable water resources are continually diminishing, and the gap between water supply and consumption demand is gradually widening. In fact, natural resources have the ability for self-treatment and can recycle certain amounts of organic and inorganic human waste; however, water quality can deteriorate rapidly when environmental conditions change. Dam construction is one of the main environmental factors that change the environmental conditions of river ecosystems and thus can affect water quality and water self-treatment. Access to the sufficient water for all is the sustainable development goal of the United Nations Environment Program (United Nations Environment Programme, 2016). There are many research studies about the need for dams in the literature, but far fewer on the potential adverse effects of dams on water quality and sedimentology. (Dai et al. 2008; Gibson and Cai 2017; Latrubesse et al. 2017; Pesce & Wunderlin, 2000; Shim et al. 2018; Skalak et al. 2013; Snoussi et al. 2002; Vörösmarty et al., 2003; Wei et al. 2009; Yang et al., 2006).

Dams affect water quality and sedimentation differently during the construction, and after the dam becomes operational. The primary objective of this study is to present a methodology to assess the impacts of the construction and operation of Çine Dam, in Aydin, Turkey, on the river flow regimes, sedimentation, and water quality of the downstream reach of B. Menderes River. For the purposes of the study, data are obtained from three gauging stations primarily based on the availability of flow, sediment concentration, and water quality data. These three stations are Çine Çakırbeyli Bridge located on the Çine tributary downstream of the Çine Dam, Aydin Bridge located on the B. Menderes River before Çine tributary merges the river, and Koçarlı Bridge, located on the B. Menderes River immediately after Çine tributary merges into the river (Fig. 1). Based on the available data, the impacts of the dam and its reservoir are investigated at the downstream of Çine Çakırbeyli Bridge station and at the Koçarlı Bridge station located after Çine tributary merges into the B. Menderes River. Coordinates of the gauging stations are presented in Table 1. In the study, water quality assessments are determined for the periods before and after the dam operation from 2006 to 2019.

Water quality indexing (WQI) is a quick and simple method for determining water quality based on a single total value and the corresponding scale (Akkoyunlu and Akiner 2012; Bharti and Katyal 2011; Dede et al. 2013; Kükrer and Mutlu 2019; Pesce and Wunderlin 2000). Water quality index (WQI) is an easily calculated single number used for the assessment of water quality. In this study, five different water quality indexing methods WQI (Brown et al. 1973), CCME-WQI, UWQI (Boyacioglu 2007), OWQI (Cude 2001), ATI (Wepener et al. 1992) are compared and examined with the values given based on Turkish Regulation on Surface Water Quality Management (Turkish Regulation 2019).

Materials and methods

Study site

Çine Dam is located on the Çine River, a tributary to B.Menderes River in Aydın, Turkey. The dam was the first roller-compacted concrete (RCC) dam, constructed for purposes of irrigation, power generation and flood protection. With a crest height of 137 m, and dam body volume of 1.41 million m^3, it ranked as the highest dam in its class in Europe, when it became operational in October 2010. Water supplied by the reservoir is used to irrigate a total of 22.358 hectares of agricultural land. Its drainage area is 1462 km^2, and the annual average precipitation is 665 mm. The volume of the reservoir is 350 ha^3, and the surface area of the reservoir is 9.34 km^2. Characteristics of the dam and its basin are provided in Table 2. Two energy production units are located in the dam each having 23.6 MW of power. Francis turbines are used in the power generation units. Annual energy production is 118 million kWh/year.

Hydrological data

The daily data sets of inflows are obtained from the DSI (General Directorate of State Hydraulic Works of Turkey) for the period of 2012–2016 at three gauging stations: Çine Çakırbeyli Bridge located on the Çine tributary downstream of the Çine Dam, at Aydin Bridge located on the B. Menderes River before Çine tributary merges with the river and at Koçarlı Bridge located on the B. Menderes River immediately after Çine tributary merges with the river (Fig. 1). Mean values for the discharges are 45.5 m^3/s for Aydın Bridge, 13.9 m^3/s for Çine Çakırbeyli and 61.5 m^3/s for Koçarli stations, respectively. Figure 2 presents the daily flow discharges monitored at these three stations.

To assess the flow time series further, decomposition analysis using ‘R programming’ is performed, and seasonality is removed from Çine tributary flow data using

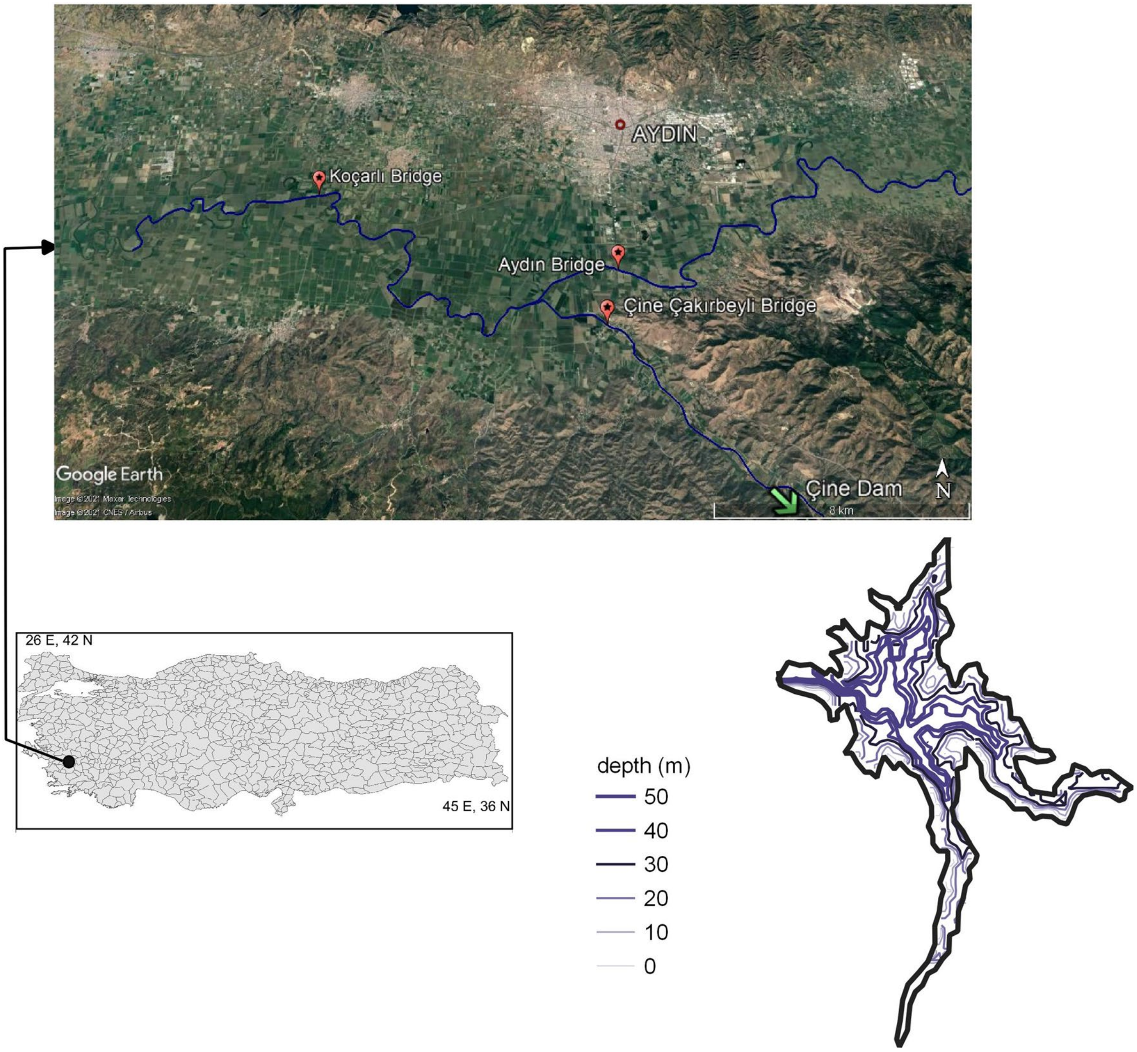

Fig. 1 Location of the Çine Reservoir and the gauging stations with the coordinates provided in Table 1

Table 1 The coordinates of the gauging stations

Station number	Station	Location	Data	Coordinates	
				North	East
S1	Koçarlı bridge	Çine river	Flow, Sediment and Water quality data	37°48′36″	27°42′47″
S2	Çakırbeyli bridge	Çine river	Flow, sediment and water quality data	37°45′50″	27°50′4″
S3	Aydin bridge	B. Menderes River	Flow and sediment data	37°47′0″	27°50′25″

the decompose function in R. Decomposing a time series involves separating it into its constituent components, which are usually a trend component and an irregular component, and if it is a seasonal time series, a seasonal component. Figure 3 presents the decomposition of the time series of the total of the flows in three steps. The top graph in Fig. 3 shows the observed values, the second graph, the trend component, the third graph, the seasonal component, and the last graph, the random or irregular component. When seasonality is removed, it can be seen a decreasing trend in inflow discharges over the years. Eq. (1) is fit for the decreasing trend as in the following ($R^2 = 0.10$):

$$Q = -0.0034 days + 157 \tag{1}$$

Table 2 Characteristics of Çine Dam and Reservoir

Physical dam properties	
Dam type	Roller-Compacted concrete dam
Height of the dam from foundation	136.5 m
Crest elevation	265 m
Crest length	362.4 m
Total dam body fill volume	1.41 × 106 m^3
Spillway type	Cascade Spillway
Spillway capacity	2578 m^3/s
Physical dam properties	
Drainage area	1462 km^2
Lake area	9.34 km^2
Volume of the reservoir	350 ha^3
Annual precipitation height	633 mm
10 years of repetitive flood	460 m^3/s
100 years of repetitive flood	690 m^3/s
Maximum flood discharge	3578 m^3/s

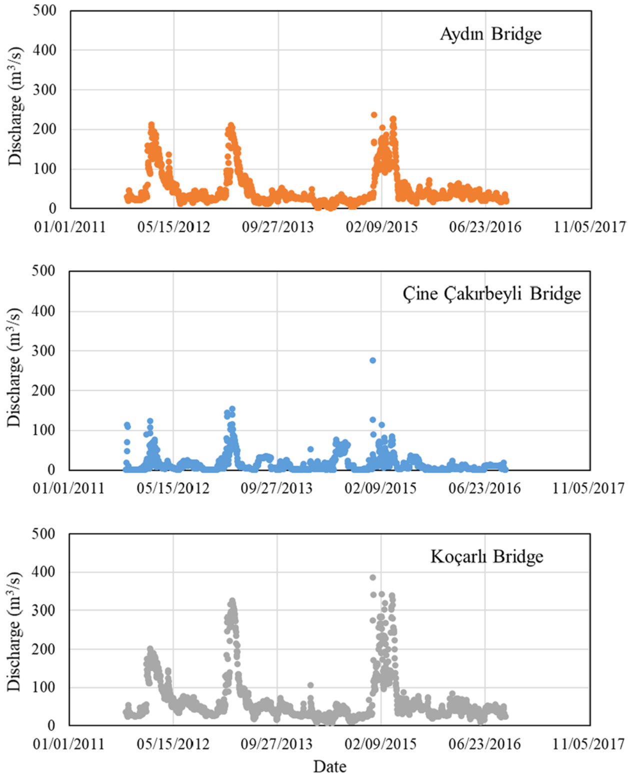

Fig. 2 Daily flow discharges monitored at Aydın, Çine Çakırbeyli and Koçarlı Bridge stations

Sediment data

Monthly Sediment data from the Çine Çakırbeyli Bridge station located downstream of the dam for the years of 2006–2019 are obtained from the reports of the EIE (General Directorate of Electrical Power Resources Survey and Development Administration of Turkey). Based on the available data, Student's t test is used to assess the statistical significance of the difference between observed sediment flux time series before and after the construction of the Çine Dam. In the analysis, sediment flux values are calculated by the multiplication of the sediment concentration with the flow data for the period 2006–2019. Table 2 presents the results of the t test applied to Çine Bridge, which indicate the probability values of $p = 0.017$ (two-tail) and $p = 0.0085$ (one-tail) both below the probability of 0.05 (5% level of significance), and therefore, the null hypothesis of no difference between means is rejected. The significant difference between the two sediment flux time series points to the impact of the dam. At the Çine Çakırbeyli Bridge station, located downstream of the dam, sediment flux monitored decreases dramatically since most of the incoming sediments were trapped within the reservoir. Monitored sediment flux mean values (discharge*sediment concentration) decrease from a mean of 17,064.6 m^3/s *ppm before the construction of the dam to 1487.6 m^3/s *ppm afterward.

Likewise, Student's t test is applied to sediment flux time series observed at Aydin Bridge located before the Çine tributary merged with the B.Menderes River. Table 3 also presents the results of the t test applied to Aydin Bridge, which indicate the probability values of $p = 0.54$ (two-tail) and $p = 0.27$ (one-tail) exceeding the probability of 0.05 (5% level of significance), and therefore, the null hypothesis of no difference between means is accepted. As interpreted from the results, the two sediment flux time series have the same statistical properties.

Figure 4 presents the relation of flow data with the sediment flux data plotted for the dates prior to the dam construction in October 2010. Plots of logarithmic values of observed discharges and sediment fluxes for the corresponding observation dates show a linear equation fitted the data as in the following ($R^2 = 0{,}85$):

$$Log(Q * C) = 0.6 * \mathrm{Log}(Q) - 0.88 \tag{2}$$

Figure 5 presents the relation of flow data with the sediment flux data plotted for the dates after the dam construction in October 2010. Plots of logarithmic values of observed discharges and sediment fluxes for the corresponding observation dates show a linear equation fitted the data, as in the following ($R^2 = 0{,}83$):

$$Log(Q * C) = 0.67 * \mathrm{Log}(Q) - 0.9 \tag{3}$$

Water quality data

One of the greater sub-basins of B.Menderes basin, the Çine basin, supports the agricultural activities of the Aydın

Fig. 3 Decomposition of the flow data monitored at the Çine Çakırbeyli Bridge station

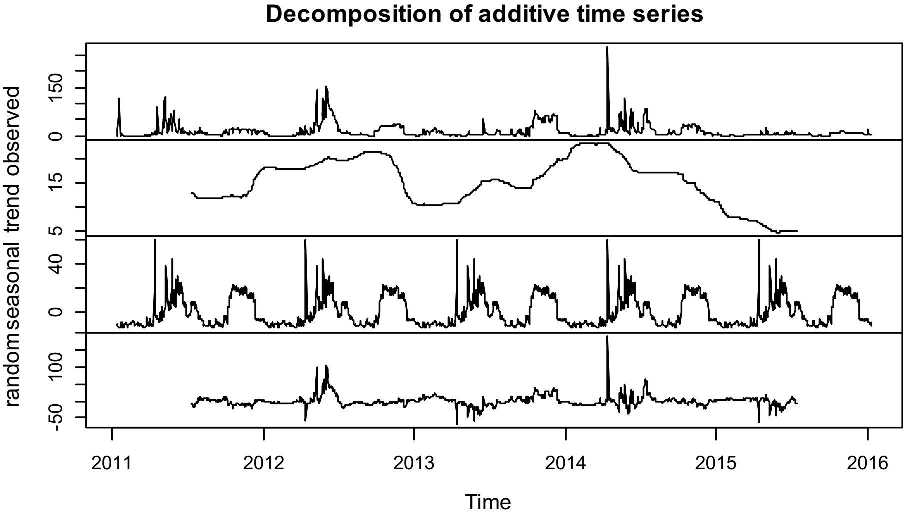

Table 3 Results of *t* test by two-sample assuming unequal variances applied to sediment fluxes observed at Çine and Aydin Bridge Stations

	Çine bridge		Aydin bridge	
	Variable 1	*Variable 2*	*Variable 1*	*Variable 2*
Mean	17,064.63	1487.59	32,493.65	51,173.92
Variance	1.92E+09	4.10E+07	3.46E+09	6.38E+10
Observations	49	62	57	75
Hypothesized Mean Difference	0		0	
df	50		84	
t Stat	2.47		−0.62	
P(T < = t) one-tail	0.01		0.27	
t Critical one-tail	1.68		1.66	
P(T < = t) two-tail	0.02		0.54	
t Critical two-tail	2.01		1.99	

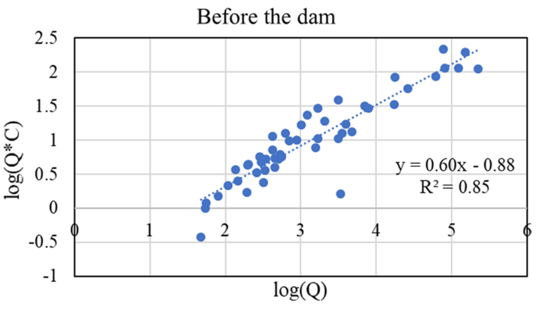

Fig. 4 The relation of the flow data with the sediment flux data observed before the construction of Çine Dam

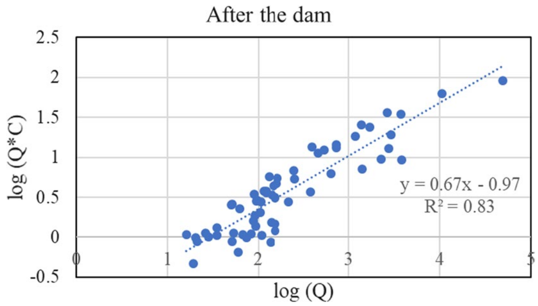

Fig. 5 The relation of the flow data with the sediment flux data observed after the construction of Çine Dam

province in Turkey. The Çine River, a major irrigation source, is fed by the Sarıgerme river and by the water coming from the Karagedik Mountains in the east of Yatağan district of Muğla and flows into the 359-km B. Menderes River. The Çine Dam and HEPP are located on Çine River, providing irrigation water for a total of 22,358 ha of agricultural land. There is an unplanned settlement problem in the basin, due to its high agricultural economic value, and most of the water pollution is attributed to the domestic wastewater originating from these settlements. In the last quarter-century, the rapid increase in the use of chemicals for various purposes in residential areas, and the use of a wide variety of organic and inorganic chemicals in the industrial zones greatly contributed to the pollution of both the soil and the water. Primary contributors are ongoing business activities in Çine Organized Industrial Zone, including furniture production, packaging, poultry farming, and fish processing.

Continuous deterioration of the soil due to local contamination and diffuse contamination (acidification and heavy metals) leads to irreversible losses and prevents the self-healing of the soil. Soil quality is of great importance for the environment and closely related to the quality of the surrounding water. Heavy metals have the affinity to attach to the finer sediments and can be transported long distances. In particular, dam construction is a major factor affecting the environmental conditions of river ecosystems and thus can affect both soil and water quality, negatively impacting the self-healing process. Natural habitat life can be adversely affected downstream of the dam and its HEPP structures. Water withdrawal by the intake structure for various purposes might deplete fish stocks. Since most of the sediments transported by the streams are trapped within the reservoir, sufficient nutrients no longer reach deltas and coastal regions, leading to the deterioration of the soil quality. Moreover, the significant intervention in the released flowrates changes the whole streambed composition, affecting water velocity, depth, and quality, thus seriously affecting the downstream aquatic life.

For all the above reasons, and considering the fact that the Çine basin is vulnerable to soil and water pollution due to human activities, it is imperative to monitor and evaluate the quality of surface waters (Republic of Turkey Ministry of Agriculture and Forestry, no date). Based on this hypothesis, the target of this study is to assess and evaluate the effect of Çine Dam and HEPP on water quality on Çine River. Two stations with periodic water quality data are selected downstream of the Çine Dam for this purpose (Fig. 1). Physicochemical and heavy metal parameters are obtained from Koçarlı Bridge station (S1) for 5 years (2006–2010) representing pre-dam construction conditions, and from Çine Çakırbeyli Bridge station (S2) for 5 years (2015–2019), representing the post-dam construction conditions. The average values obtained for each parameter are presented in Table 4 and Table 5 for both S1 and S2 stations, respectively.

Tables 4 and 5 also present the evaluation of the water quality parameters with respect to the Turkish Water Pollution Control Regulation and the standard limit values as provided by TS266, the Turkish Water Pollution Control Regulation, and WHO (EPA 2009; TSE 2005; WHO 2009, 2011a, 2011b; Turkish Regulation 2019).

Water quality index methods

Water quality indexing is widely used to present complex water quality data in a more comprehensible form and provides decision-makers and non-technical managers of water resources with concise information about water quality status. The concept of categorizing water according to the degree of pollution first emerged in Germany in the mid-nineteenth century (Lumb et al. 2011). In these studies, the presence or absence of certain organisms in the water was used as an indicator of water suitability. These classification systems are generally divided into two groups, dealing either with the pollution level or with living communities of macroscopic or microscopic organisms. Horton first proposed the water quality index in 1965, and since then, many different water quality index calculation methods have been developed in the literature. Horton's (1965) index is based on the ten most frequently measured variables: population percentage, dissolved oxygen (DO), pH, fecal coliforms (FC) count, electrical conductivity (EC), carbon chloroform extract, alkalinity (pH), chloride, temperature, and "significant contamination." According to Horton (1965), secondary indicators can be added if additional information is required. He determined a rating scale with a sub-index between 0 and 100 for each variable. Horton's index is recognized worldwide as a tool for comparative assessment of water quality conditions and water pollution abatement programs.

Later, Brown et. al (1970) created a new water quality index based on nine water quality variables: dissolved oxygen (DO), fecal coliform (FC), pH, biochemical oxygen demand (BOD), temperature, total phosphate (PO_4) and nitrate concentrations (NO_3), turbidity (Turb), and total solids (TS). Five types of classes: red (very weak), orange (weak), yellow (average), green (good) and blue (perfect) were used to indicated water quality (WQ) based on the professional opinion of 142 experts.

Although many water quality indexes are present in the literature, the analysis in this study utilized only five: Weighted Arithmetic Index (WAI-WQI), Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI), Universal Water Quality Index (UWQI), Oregon Water Quality Index (OWQI) and Aquatic Toxicity Index (ATI). These indexes are applied, and their results are used to evaluate the water quality of the Çine River before and after the dam operation.

Weighted arithmetic index method (WAI-WQI)

This method, developed by Brown et al. (1973) is based on the selection of parameters, developing a common scale and determining the weight effects. It is currently widely used by scientists and administrative institutions. In this index, a mathematical equation is utilized that scores water quality by number, with data from multiple water quality parameters. It uses a smaller number of more commonly monitored water quality parameters compared to other systems. Here, unit weight factors are calculated for each selected parameter by the following equation.

$$W_n = \frac{K}{S_n} \quad (4)$$

Table 4 The average water quality parameters in years, corresponding standards for S1

Parameters	2006		2007		2008		2009		2010		Limit values**		Applied Method***
	avg	SWQ*	avg	SWQ*	avg	SWQ*	avg	SWQ*	avg	SWQ*			
AluminumAl (µg/L)	358.33	**I**	0.00	**I**	21.25	**I**	0.00	**I**	10.00	**I**	200	TS266	1,2
Ammonium, NH4-N (mg/L)	0.11	**I**	0.57	**II**	0.20	**I**	0.44	**II**	0.40	**II**	0.50	TS266	1,2,4,5
Arsenic, AS (µg/L)	–	–	24.90	**II**	23.59	**II**	10.61	**I**	9.25	**I**	10	TS266	1,2,3
Barium, Ba (µg/L)	–	–	–	–	–	–	63.89	**I**	–	–	1000	TR,2019	1,2
Biochemical Oxygen Demand, BOD5 (mg/L)	3.83	**I**	9.90	**III**	6.90	**II**	5.60	**II**	9.00	**III**	4	TR,2019	1,2,3,4
Boron, B (mg/L)	0.28	**I**	0.56	**I**	0.31	**I**	0.27	**I**	0.11	**I**	1	TS266	1,2
Cadmium, Cd (µg/L)	1.00	**I**	0.00	**I**	0.06	**I**	0.11	**I**	0.26	**I**	5	TS266	1,2,5
Calcium, Ca++ (mg/L)	97.88	–	96.01	–	111.73	–	70.48	–	94.19	–	200	WHO	1,2
Chemical oxygen demand, COD (mg/L)	19.90	**I**	55.43	**III**	34.67	**II**	17.03	**I**	17.07	**I**	25	TR,2019	1,2,3,4
Chloride, Cl- (mg/lt)	98.68	**II**	117.01	**IV**	116.10	**IV**	66.18	**II**	86.42	**IV**	25	TR,2019	1,2
Chromium, Cr (µg/L)	48.00	**II**	4.80	**I**	0.26	**I**	6.41	**I**	10.35	**I**	50	TS266	1,2,5
Cobalt, Co (µg/L)	–	–	–	–	–	–	1.69	**I**	–	–	10	TR,2019	1,2
Color (Pt–Co)	–	–	–	–	–	–	30.83	**II**	40.00	**II**	20	TS266	1,2
Copper, Cu (µg/L)	18.00	**I**	33.80	**II**	7.87	**I**	11.76	**I**	22.35	**II**	2000	TS266	1,2,5
Dissolved oxygen, DO (mg O2/l)	7.85	**II**	7.44	**II**	7.39	**II**	7.14	**II**	7.76	**II**	8	TR,2019	1,2,3,4,5
E-Coli (EMS/100 ml)	500	**III**	500	**III**	1000	**III**	17,000	**IV**	0	**I**	20	TS266	1,2,4
Electrical conductivity, EC (mikromhos/cm)	1355	–	1469	–	1523	–	953	–	1214	–	2500	TS266	1,2,4,5
F-Strp (EMS/100 ml)	100	IIII	50	**II**	175	**II**	6050	**IV**	3690	**IV**	20	TR,2019	1,2,4
Iron, Fe (µg/L)	114.69	**I**	85.40	**I**	251.00	**I**	1279.07	**III**	115.00	**I**	200	TS266	1,2
Lead, Pb (µg/L)	13.00	**II**	3.70	**I**	0.88	**I**	3.11	**I**	7.50	**I**	10	TS266	1,2,5
Magnesium, Mg++(mg/L)	72.15	–	85.72	–	87.41	–	54.73	–	65.47	–	200	WHO	1,2
Manganese, Mn (µg/L)	80.00	**I**	261.00	**II**	360.71	**II**	113.41	**II**	219.83	**II**	50	TS266	1,2
Mercury, Hg (µg/L)	–	–	–	–	0.20	**II**	–	–	–	–	1	TS266	1,2,3
Nickel, Ni (µg/L)	–	–	–	–	–	–	16.89	**I**	–	–	20	TS266	1,2,5
Nitrate, NO3-N (mg/L)	1.70	**I**	1.46	**I**	2.81	**I**	2.93	**I**	2.47	**I**	50.00	TS266	1,2,3,4
Nitrite, NO2-N (mg/L)	0.03	**II**	0.03	**III**	0.07	**III**	0.05	**III**	0.02	**III**	0.5	TS266	1,2
Organic Material, pV (mg O2/l)	3.37	–	4.64	–	3.48	–	4.78	–	5.11	–	5	WHO	1,2
pH	7.95	**I**	7.82	**I**	8.26	**I**	8.02	**I**	8.10	**I**		TS266	1,2,3,4,5
Phosphate, PO4 (mg/L)	0.36	–	0.56	–	0.78	–	0.44	–	3.24	–	0.40	TR,2019	1,2,3,4,5
Potassium, K+(mg/L)	8.95	–	10.30	–	11.00	–	6.87	–	8.32	–	n.a		
Sodium, Na+(mg/L)	97.77	**I**	109.94	**I**	115.10	**I**	59.87	**I**	85.63	**I**	200	TS266	1,2
Sulfates, SO4 (mg/L)	270.57	**III**	314.58	**III**	335.21	**III**	178.50	**I**	275.15	**III**	250	TS266	1,2
Total Coli, T-Coli (EMS/100 ml)	2000	**II**	1000	**II**	12,500	**II**	64,000	**III**	279,600	**IV**	100	TR,2019	1,2,4
Total Dissolved Solids, TDS (mg/L)	866.67	**II**	1094.44	**II**	1135.00	**II**	685.00	**II**	896.17	**II**	500	TR,2019	1,2,4
Total Hardness, TH (mg/l CaCO3)	540.83	–	605.00	–	638.13	–	400.83	–	461.00	–	500	TR,2019	1,2
Turbidity, Turb (NTU)	–	–	–	–	–	–	30.83	–	234.72	–	50	TS266	1,2

Table 4 (continued)

Parameters	2006		2007		2008		2009		2010		Limit values**		Applied Method***
	avg	SWQ*	avg	SWQ*	avg	SWQ*	avg	SWQ*	avg	SWQ*			
Vanadium, V (µg/L)	–	–	–	–	–	–	4.88	–	–	–	n.a		
Zinc, Zn (µg/L)	13.00	**I**	55.70	**I**	23.87	**I**	72.79	**I**	487.88	**II**	200	TR,2019	1,2,5

*Qualifications were given based on Turkish Regulation on Surface Water Quality Management (Turkish Regulation 2019) (SWQ); **Limit values were given based on (TS 266), (TurkishRegulation 2019), (WHO 2011a) and (WHO 2011b); ***Water quality parameters used for Water Quality Index Methods (1:WQI, 2:CCEM-WQI, 3:UWQI, 4:OWQI, 5:ATI); n.a. not available

where S_n is the standard desirable value of the nth parameters and,

$$K = \frac{1}{1/S_1 + 1/S_2 + 1/S_3 + \cdots + 1/S_n} = \frac{1}{\sum \frac{1}{S_n}} \tag{5}$$

Summation of all the selected parameters' unit weight factors should be equal to 1 ($W_n = 1$). For the second step, the sub-index (Q_n) values are calculated using the formula.

$$Q_n = \frac{\left[\left(V_n - V_0\right)\right]}{\left[\left(S_n - V_0\right)\right]} * 100 \tag{6}$$

where V_n is the mean concentration of the nth parameters, and V_0 is the actual value of the parameters in pure water (generally $V_0 = 1$ except pH and DO. For pH and DO $V_0 = 7$ and $V_0 = 14.6$ mg/l, respectively). With combining first and second step, WQI is calculate as follows:

$$WQI = \frac{\sum W_n Q_n}{\sum W_n} \tag{7}$$

Later, Brown et al. (1973) modified the arithmetic sum to the geometric sum, which is more precise when a single variable exceeds the norm (Lumb et al. 2011). Brown et al. (1973)'s work was supported by the National Sanitation Foundation and named as NSFWQI index (Brown et al., 1973). Water quality classification corresponding to this index is given in Table 6.

Canadian council of ministers of the environment water quality index (CCME-WQI)

The Canadian Water Quality Index (CCME-WQI) is a consistent method formulated by the Canadian government to communicate complex water quality information and facilitate communication to both management and the public (CCME 2001a, 2001b; Lumb et al. 2011). This method has been developed to evaluate surface water according to specific rules for the protection of aquatic organisms. The index produces a number ranging between 0 (worst water quality) and 100 (best water quality). This range is divided into 5 descriptive categories to simplify the presentation. The parameters for the various measurements may differ from region to region depending on the subjects and local conditions. At least four parameters sampled on four occasions are required to calculate this index.

Conceptually, CCME-WQI includes three factors (CCME 2001a, 2001b). Factor 1(F_1) expresses the percentage of the parameters exceeding the target value given in the water quality legislation, according to the total parameters. Factor 2 (F_2) states the frequency, i.e., the number of times the observed value falls outside of the acceptable limits. Factor

Table 5 The average water quality parameters in years, corresponding standards for S2

Parameters	2015		2016		2017		2018		2019		Limit values**		Applied Method***
	Avg.	SWQ*	Avg.	SWQ*	Avg.	SWQ*	Avg.	SWQ*	Avg.	SWQ*			
AluminumAl (μg/L)	431.34	**III**	208.13	**I**	247.86	**I**	281.50	**I**	24.36	**I**	200	TS266	1,2
Ammonium, NH4-N (mg/L)	0.16	**I**	1.02	**II**	1.00	**II**	0.03	**I**	0.05	**I**	0.50	TS266	1,2,4,5
Arsenic, AS (μg/L)	6.04	**I**	8.73	**I**	12.30	**I**	7.81	**I**	4.49	**I**	10	TS266	1,2,3
Barium, Ba (μg/L)	40.95	**I**	36.87	**I**	74.02	**I**	42.53	**I**	34.92	**I**	1000	TR,2019	1,2
Biochemical Oxygen Demand, BOD5 (mg/L)	8.75	**III**	5.25	**II**	8.75	**III**	7.50	**II**	5.00	**II**	4	TR,2019	1,2,3,4
Boron, B (mg/L)	0.03	**I**	0.03	**I**	0.17	**I**	0.14	**I**	0.09	**I**	1	TS266	1,2
Cadmium, Cd (μg/L)	0.07	**I**	0.05	**I**	0.07	**I**	0.20	**I**	0.10	**I**	5	TS266	1,2,5
Calcium, Ca++ (mg/L)	57.64	_	57.86	_	49.73	_	55.94	_	49.83	_	200	WHO	1,2
Chemical oxygen demand, COD (mg/L)	13.33	**I**	13.46	**I**	25.50	**II**	26.60	**II**	12.90	**I**	25	TR,2019	1,2,3,4
Chloride, Cl- (mg/lt)	17.56	**I**	21.23	**I**	28.92	**II**	29.64	**II**	14.21	**I**	25	TR,2019	1,2
Chromium, Cr (μg/L)	5.30	**I**	2.50	**I**	4.95	**I**	3.52	**I**	1.95	**I**	50	TS266	1,2,5
Cobalt, Co (μg/L)	0.87	**I**	0.69	**I**	1.42	**I**	0.70	**I**	0.35	**I**	10	TR,2019	1,2
Color (Pt–Co)	22.50	**II**	8.48	**II**	7.70	**II**	7.92	**II**	7.93	**II**	20	TS266	1,2
Copper, Cu (μg/L)	7.68	**I**	1.74	**I**	8.32	**I**	13.17	**I**	78.56	**III**	2000	TS266	1,2,5
Dissolved oxygen, DO (mg O2/l)	9.79	**II**	5.39	**III**	6.20	**II**	7.39	**II**	7.86	**II**	8	TR,2019	1,2,3,4,5
E-Coli (EMS/100 ml)	0	**IV**	300	**III**	1916	**III**	1780	**III**	2420	**IV**	20	TS266	1,2,4
Electrical conductivity, EC (mikromhos/cm)	52	_	48	_	142	_	51	_	35	_	2500	TS266	1,2,4,5
F-Strp (EMS/100 ml)	0	**I**	1500	**III**	990	**III**	2046	**IV**	1212	**III**	20	TR,2019	1,2,4
Iron, Fe (μg/L)	771.65	**II**	429.58	**II**	755.74	**II**	558.01	**II**	70.86	**I**	200	TS266	1,2
Lead, Pb (μg/L)	3.12	**I**	3.96	**I**	6.51	**I**	0.95	**I**	0.32	**I**	10	TS266	1,2,5
Magnesium, Mg++ (mg/L)	10.80	–	13.72	–	12.23	–	13.52	–	11.10	–	200	WHO	1,2
Manganese, Mn (μg/L)	160.96	**II**	218.06	**II**	243.07	**II**	209.91	**II**	91.43	**I**	50	TS266	1,2
Mercury, Hg (μg/L)	0.14	**II**	0.07	**I**	0.46	**II**	0.39	**II**	3.55	**IV**	1	TS266	1,2,3
Nickel, Ni (μg/L)	20.65	**II**	6.68	**I**	10.94	**I**	2.72	**I**	2.87	**I**	20	TS266	1,2,5
Nitrate, NO3-N (mg/L)	1.09	**I**	0.63	**I**	0.94	**I**	1.45	**I**	1.29	**I**	50.00	TS266	1,2,3,4
Nitrite, NO2-N (mg/L)	0.07	**IV**	0.02	**III**	0.25	**IV**	0.16	**IV**	0.02	**III**	0.5	TS266	1,2
Organic Material, pV (mg O2/l)	6.54	–	4.15	–	6.25	–	5.02	–	6.03	–	5	WHO	1,2
pH	7.72	**I**	7.72	**I**	7.61	**I**	7.63	**I**	7.86	**I**		TS266	1,2,3,4,5
Phosphate, PO4 (mg/L)	0.28	–	0.15	–	0.43	–	0.37	–	0.13	–	0.40	TR,2019	1,2,3,4,5
Potassium, K+ (mg/L)	7.39	–	5.98	–	8.88	–	8.25	–	3.04	–	n.a		
Sodium, Na+ (mg/L)	25.65	**I**	18.88	**I**	26.61	**I**	30.58	**I**	13.68	**I**	200	TS266	1,2
Sulfates, SO4 (mg/L)	42.03	**I**	54.82	**I**	43.57	**I**	48.84	**I**	41.11	**I**	250	TS266	1,2
Total Coli, T-Coli (EMS/100 ml)	3150	**II**	10,200	**II**	9592	**II**	2420	**II**	2420	**II**	100	TR,2019	1,2,4
Total Dissolved Solids, TDS (mg/L)	297.18	**I**	295.36	**I**	290.34	**I**	335.52	**I**	241.68	**I**	500	TR,2019	1,2
Total Hardness, TH (mg/l CaCO3)	188.23	–	200.79	–	174.48	–	195.35	–	170.10	–	500	TR,2019	1,2
Turbidity, Turb (NTU)	16.73	–	10.06	–	25.00	–	22.15	–	29.50	–	50	TR,2019	1,2

Table 5 (continued)

Parameters	2015		2016		2017		2018		2019		Limit values**		Applied Method***
	Avg.	SWQ*	Avg.	SWQ*	Avg.	SWQ*	Avg.	SWQ*	Avg.	SWQ*			
Vanadium, V (μg/L)	1.38	–	1.31	–	4.60	–	2.26	–	1.46	–	n.a		
Zinc, Zn (μg/L)	75.76	I	36.10	I	138.97	I	15.21	I	8.79	I	200	TR,2019	1,2,5

*Qualifications were given based on Turkish Regulation on Surface Water Quality Management (TurkishRegulation 2019) (SWQ); **Limit values were given based on (TS 266), (TurkishRegulation 2019), (WHO 2011a) and (WHO 2011b); ***Water quality parameters used for Water Quality Index Methods (1:WQI, 2:CCEM-WQI, 3:UWQI, 4:OWQI, 5:ATI); n.a. not available

Table 6 Water quality index methods classifications

SWQ*		WQI		CCME-WQI		UWQI		OWQI		ATI	
I	High quality	0–25	Excellent	95–100	Excellent	95–100	Excellent	90–100	Excellent	0–50	Totally unsuitable for normal fish life
II	Less polluted	26–50	Good	80–94.9	Good	75–94	Good	85–89	Good	51–59	Suitable only for hardly fish species
III	Polluted	51–100	Poor	65–79.9	Fair	50–74	Fair	80–84	Fair	60–100	Suitable for all fish life
IV	Most polluted	76–100	Very Poor	45–64.9	Marginal	25–49	Marginal	60–79	Poor		
		Above 100	Unsuitable for drinking and fish culture	0–44.9	Poor	0–24	Poor	10–59	Very Poor		

*Turkish Regulation on Surface Water Quality Management (TurkishRegulation 2019) (SWQ)

3 (F_3) is the width of the divergence or the amount by which targets are not met. It refers to the number of failed test values that exceed the given limit value. The calculation formula of the index is as follows:

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) * 100 \tag{8}$$

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right) * 100 \tag{9}$$

F_3 can be calculated in three sub-steps:

1) The number of experiments where the variable value does not meet the target value is called the "excursion" and is calculated as follows.

a. When the test value must not exceed the objective:

$$excursion = \frac{Failed\ test\ value_i}{Objective_i} - 1 \tag{10}$$

b. When the test value must not fall below the objective:

$$excursion = \frac{Objective_i}{Failed\ test\ value_i} - 1 \tag{11}$$

c. When the objective value is zero:

$$excursion = Failed\ test\ value_i \tag{12}$$

2) The second step is calculating the ratio of the sum of excursions (nse).

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{Total\ number\ of\ tests} \tag{13}$$

3) The final step is calculating F_3 with nse value.

$$F_3 = \frac{nse}{0.01nse + 0.01} \tag{14}$$

Finally, CCME-WQI can be computed as follows:

$$CCME - WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right) \tag{15}$$

Water quality classification for CCME (2001a) is given in Table 6.

Universal water quality index (UWQI)

Boyacioglu (2007) developed the Universal Water Quality Index (UWQI) Method to determine water quality for a specific use, e.g., drinking water supply. The index was developed according to the European Community Standard. The temporary weight factors are ranged from 1 to 4 on a basic scale of importance. On this scale, 1, 2, 3 and 4 denote, respectively, little, average, great and very great importance. Each weight is then divided by the sum of all weights to arrive at the final weight factor. For the assessment of the quality of surface water sources, UWQI uses twelve significant indicator parameters: cadmium, cyanide, mercury, selenium, arsenic, fluoride, nitrate, dissolved oxygen, BOD, phosphorus, pH, and total coliform. The aggregation function is represented by the following equation:

$$UWQI = \sum_{i=1}^{n} w_i I_i \tag{16}$$

where w_i is the weight factor, and I_i is the sub-index for ith parameter. The equations used for the sub-index values are presented in Boyacioglu (2007). Water quality classification corresponding to this index is given in Table 6.

Oregon water quality index (OWQI)

The Oregon Water Quality Index was developed in the 1970s by the Oregon Environment Department to determine water quality and trends for legally required water quality assessment reports (Cude 2001). However, the original OWQI was discontinued in 1983, as its calculation required a great many resources. With advances in computer technology, advanced data visualization and visualization tools, and a better understanding of water quality, OWQI was updated in 1995; improvements included refining the original sub-index, adding the temperature and total phosphorus sub-index, and improving the weighting factors. OWQI is calculated in two steps. Raw analytical results with different measurement units for each variable are converted into unitless sub-index values. These values range from 10 (worst case) to 100 (ideal). These subclasses are then combined to give a single WQI value ranging from 10 to 100. OWQI merges measurements of eight water quality parameters: temperature, dissolved oxygen, BOD, pH, ammonia, nitrate nitrogen, total phosphorus, total solids, and fecal coliform, expressing them in a single value (Cude 2001). Oregon Water Quality Index is calculated using the following equation:

$$QWQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SI_i^2}}} \tag{17}$$

where SI is the sub-index, and n is the number of variables. The Oregon Water Quality Index (OWQI) aims to provide an understanding of water quality issues and of the state of water quality by establishing a score that describes water quality status and evaluates water quality change. The classification of water quality for the Oregon Water Quality Index (OWQI) Method is given in Table 6 (Cude 2001; Lumb et al. 2011).

Aquatic toxicity index (ATI)

Wepener et al. (1992) developed an aquatic toxicity index to determine the evolution of toxicological effects of selected water quality parameters on the aquatic environment. This index aims at the protection of aquatic life, and it measures the toxic effects of different water quality variables on aquatic organisms, especially fish, as indicators of the health of an aquatic ecosystem. Three steps were followed for the development of an aquatic toxicity index determinant (water quality parameter) transformation, determinant selection, and determinant aggregation. The water quality parameters were selected as pH, dissolved oxygen, turbidity, ammonium, total dissolved salts, fluoride, potassium, orthophosphates, total zinc, manganese, chromium, copper, lead, and nickel. All these variables are in line with the requirements of aquatic life and should remain within the range of values appropriate for an aquatic ecosystem. The most efficient method of transforming information about individual parameter concentrations is to select or obtain rating curves for each parameter. The values obtained from rating curves had to be aggregated in some way to produce a final index score. The Solway Modified Unweighted Additive Aggregation function is used as the aggregation technique (House and Ellis 1980) as in the following:

$$ATI = \frac{1}{100}\left(\frac{1}{n}\sum_{i=1}^{n} q_i\right)^2 \tag{18}$$

where ATI is the final index score, q_i is the quality of the ith parameter (sub-index value between zero and 100), and n is the number of water quality parameters in the indexing system. The classification of water quality is given in Table 6. For the sub-index equations, the reader is referred to Wepener et al. (1992).

Results and discussion

This study evaluated the effects of the Çine Dam on its downstream water quality, a tributary that merges into B. Menderes Basin, an area of high agricultural economic value. For this purpose, two stations downstream of the Çine Dam, with periodic water quality data, were selected (Fig. 1). Physico-chemical and heavy metal parameters were obtained from Koçarlı Bridge station (S1) for 5 years (2006–2010) representing the conditions before the dam construction, and from Çine Çakırbeyli Bridge station (S2) for 5 years (2015–2019) representing the post-construction conditions. Based on this data, annual water quality parameters presented in Tables 4 and 5 were evaluated according to the Turkey Water Pollution Control Regulation water quality class, and their variation in time is presented in Fig. 6.

The Mann–Whitney U test was used to assess whether there are significant differences in water quality parameters before and after the dam construction (Table 7). As can be seen in the table, there were significant differences ($p < 0.005$) between conditions before and after dam operation for the monitored values of B, Ca, Cl, EC, Mg, NO3, pH, PO4, Na, SO4, TDS and TH. However, no such significant change was observed in the monitored values of Al, NH4, As, BOD, Cd, COD, Cr, Cu, DO, E-Coli, F-Strp, Fe, Pb, Mn, NO_2 and pV ($p > 0.05$).

Of these parameters, pH is one of the most important in water quality assessments and it affects many chemical and biological processes in water (Bigham et al. 1996; Spellman 2017). As the pH varies with water temperature, it does not directly affect the land use (WHO 2011b). Although pH does not have a direct effect on human health, it affects many chemical and biological processes in water, and its role in water chemistry is linked to corrosion, alkalinity, hardness and CO_2 balance (Dincer 2014). The average pH value in the basin fell into class—I, according to the classification of the Turkey Water Pollution Control Regulation. After the dam construction, observed pH values decreased a significant amount according to the Mann–Whitney U test. A decrease in pH value (i.e., acidic water) affects some chemicals and metals, such as sulfate (SO_4), nitrate (NO_3) and aluminum (Al). These parameters were also observed to decrease after the dam operation. Lower water temperature and a higher pH value may also have caused the high nitrite NO_2 amount before the operation, as nitrite combined with natural waters rapidly transforms into nitrate.

Nitrogen in water mainly originates from the amino groups of vegetable proteins that decompose in the soil. Nitrogen compounds are found in aquatic environments as ammonia (NH_4), nitrate (NO_3) and nitrite (NO_2). Agricultural, industrial and sewage waste discharge is the main sources of ammonia pollution in the environment. The amount of nitrogen in wastewater depends on proteinaceous substances and urea. With the decomposition of these substances, nitrogen turns into ammonia (NH_4), one of the constituents of treated domestic wastewater, which is carried into water by soil erosion. The increase in ammonia (NH_4) values was observed in 2016 and 2017, and an increase in nitrite (NO_2), in 2017 and 2018, suggesting a more intense discharge of domestic and industrial waste into the stream in these years. For these two nitrogen compounds, the Mann–Whitney U test showed no significant change after the dam operation, whereas for the third form of nitrogen, nitrate (NO3) decreased significantly after the dam operation.

Intensive application and excessive use of chemical pesticides in agricultural activities lead to increased nitrogen and

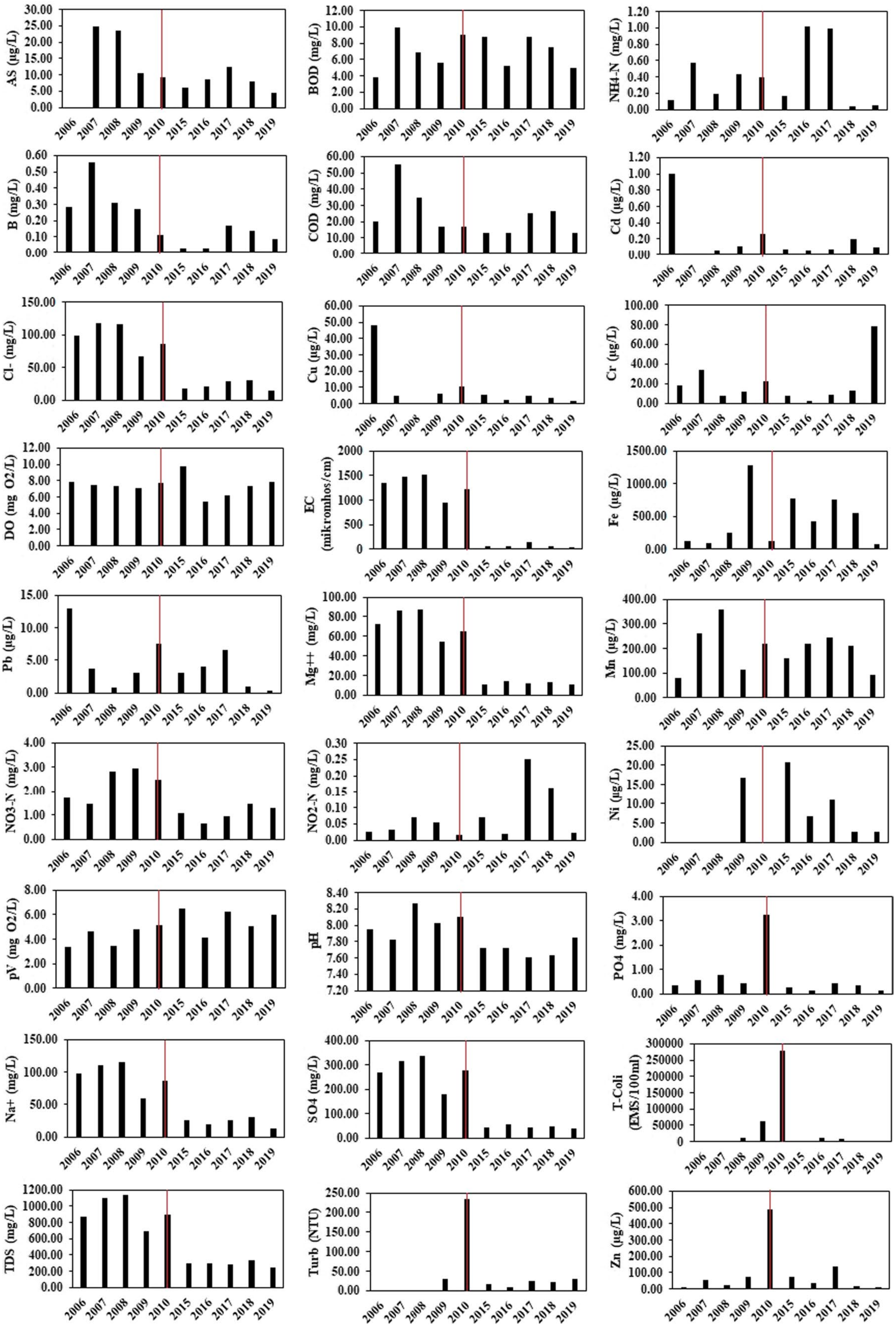

Fig. 6 Change in yearly mean parameters (Dam construction year is 2010 represented with the red line)

Table 7 Mann–Whitney *U* test results for water quality parameters between before and after dam operation. Color fonts indicate the significant difference ($P < 0.05$)

Parameters	Before / After dam operation
Al	0.095
NH4-N	0.841
AS	0.063
BOD5	0.841
B	**0.032**
Cd	0.690
Ca++	**0.008**
COD	0.222
CL-	**0.008**
Cr	0.310
Cu	0.421
DO	0.841
E-Coli	**0.008**
EC	0.841
F-Strp	1.000
Fe	0.548
Pb	0.548
Mg++	**0.008**
Mn	0.69
NO3-N	**0.008**
NO2-N	0.548
pV	0.095
pH	**0.016**
PO4	**0.032**
Na++	**0.008**
SO4	**0.008**
TDS	**0.008**
TH	**0.008**

phosphorus loads, causing eutrophication. Eutrophication is the excessive proliferation of plankton and algae in any large water ecosystem, such as lakes, due to nutrient abundance, for various reasons. Due to the stagnant water in the reservoirs, the suspended solid material will rapidly collapse and deposit in the reservoir. As a result, the increase in sediment particles serves as the main pollutant, accompanied by increased phosphate eutrophication (Nurnberg 1988; Shim et al. 2018; Zhang et al. 2014). In the absence of large anthropogenic food inputs, eutrophication is typically temporary and subsides within a few years after reservoir formation. Although phosphate (PO_4) values remained below the limits for the evaluation period, a significant peak was observed in 2010 immediately after the construction, suggesting that chemical–structural material entered the stream during the construction. After the year 2010, the suspended sediment concentration and the phosphate amount in the Çine River decreased as sediments were trapped within the reservoir; the Mann–Whitney U test showed that phosphate values decreased significantly after the dam operation ($p < 0.05$).

Construction of the dam also impacted another important water quality parameter, electrical conductivity (EC), a measure of the salinity of the water and the total dissolved solids (TDS) (Dede et al. 2013). EC is related to the total concentration of charged ionic species in water, and as it increases, the greater salinity of water used for irrigation leads to soil deterioration. According to the Mann–Whitney U test, the EC and TDS values decreased significantly after the dam operation ($p < 0.05$) and remained below the standard limits in all years.

Special attention needs to be given to the dissolved oxygen (DO), an important control parameter for water quality. DO regulates biological activities in surface waters for the survival of aquatic life. Organic waste can cause the DO levels to decrease, as can the release of warm water used in industrial processes, which may increase the water temperature (Kale 2016). After Çine Dam started its operation in 2010, DO concentrations in the Çine River did not change significantly according to the Mann–Whitney U test ($p > 0.05$). Biochemical oxygen demand (BOD), which is another important water quality parameter, can be defined as the amount of oxygen that microorganisms consume by decomposing organic substances in the water. High BOD concentration may cause death of some aquatic organisms, such as fish, as well as increased eutrophication (Cude 2001; TSE 1996a). The BOD parameter is used to determine the degree of contamination by industrial and sewage wastes which do not contain toxic substances. Chemical oxygen demand (COD) is another parameter used to determine the degree of organic pollution of domestic and industrial wastewater. Since COD can be assessed quickly, it is more practical than BOD, and, unlike BOD, the COD value of water may also include some non-biodegradable substances. Unsurprisingly, the BOD and COD values originating from domestic wastewater have at times increased over the years due to intensive agricultural practices in the basin and the settlements. After the construction of the dam, BOD and COD values did not show a significant change according to the Mann–Whitney U test ($p > 0.05$).

Sulfate (SO_4) occurs naturally in the environment and its excess causes sulfate pollution in the water, caused mainly by industrial discharge into the stream. On the other hand, chloride (Cl) is one of the anions commonly found in surface waters. Increases in the amount of chloride (Cl) in the environment may be due to the mixing of seawater with groundwater, agricultural activities, human and animal feces and industrial waste. The amount of sulfate (SO4) and chloride (Cl) exceeded the limit values before the dam operation, but fell below the limit values after, and the change was significant, according to the Mann–Whitney U test ($p < 0.05$).

Calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K) are among the elements essential for the human body and are abundant on the earth surface. Total hardness is expressed as the sum of the calcium (Ca) and magnesium (Mg) concentrations. While sodium (Na) and magnesium (Mg) amounts exceeded the limit values before the dam operation, they fell below the limit values after, and the change was significant according to the Mann–Whitney U test ($p < 0.05$).

In this study, there was a comparison before and after the dam operation of the following trace elements: (aluminum (Al), arsenic (As), barium (Ba), boron (B), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), and zinc (Zn)). According to the Mann–Whitney U test, Al, As, Cd, Cr, Cu, Fe, Pb, and Mn values did not change significantly ($p > 0.05$), but Ba, B, Co, Hg, Ni, and Zn values significantly decreased ($p < 0.05$). Considering the 10 years of research, it has been observed that some trace elements generally remain within the limit values, despite fluctuations in some years. Aluminum is frequently used in the automotive, and electrical industries, and in the production of metal alloys, so it is found in untreated industrial wastes. The higher aluminum (Al) value in 2015 suggests an increased discharge of industrial wastewater in that year. As for zinc (Zn) values, the most striking increase was observed in 2010, immediately after the dam construction. This observation once again points to the release of chemical and building materials into the downstream just before the dam became operational. The increase in Cd, Cu and Pb values in 2006 also suggests the discharge of industrial wastewater into the stream bed in those years.

Animal husbandry, which is a sub-branch of agricultural activities, is seen as a source of pollution in drinking water basins. If precautions are not taken in the basins where livestock activities are carried out, there is the danger rapid pollution of water resources. Pollution occurs when animal wastes mix with surface water through precipitation from barns. Also, antibiotics are used regularly in animal husbandry. It is quite possible that animal urine and fecal wastes can enter the surface waters via rainfall. As can be seen from Table 6, the bacteriological analysis results (E-Coli, F-Strp, and Total Coli) were well above the limit values, and in fact, Çine River waters are not very suitable for untreated use. These values did not change significantly according to the Mann–Whitney U test after the dam operation ($p > 0.05$), and annual amounts are almost always high. In particular, the increase in E-Coli, F-Strp, and Total Coli values in 2010 supports the idea that chemical–structural material used in the dam construction were deposited in the riverbed just before the operation in 2010.

Discharge of agricultural and industrial waste into the surface water can cause a change in color and turbidity, which may indicate a serious problem (WHO 2011b). Turbidity is also caused by suspended or colloidal organic and/or inorganic substances in water. Since microorganisms can adhere to particles, turbidity may be a sign of possible microbial contamination (Akkoyunlu & Akiner 2012; Cude 2001; TSE 2005; WHO 2011b). The 10-year color and turbidity parameters showed values well below the limits, except for a point increase in 2010 immediately after the dam construction, and this spike was also attributable to the discharge of chemical–structural material into the streambed.

Comparison of water quality index methods

In this study, five different water quality index methods are applied and compared to evaluate the water quality of the Çine River before and after the dam operation. The methods are as follows: Weighted Arithmetic Index (WAI-WQI), Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI), Universal Water Quality Index (UWQI), Oregon Water Quality Index (OWQI) and Aquatic Toxicity Index (ATI) methods.

Water quality indexes are calculated with WAI-WQI and CCME-WQI methods by using 36 parameters (Al, NH_4 -N, As, Ba, BOD, B, Cd, Ca, COD, Cl, Cr, Co, Cu, Pt-Co, DO, E-Coli, EC, F-Strp, Fe, Pb, Mg, Mn, Hg, Ni, NO_3, NO_2, pV, pH, PO_4, Na, SO_4, T-Coli, TDS, TH, Turbidity and Zn). Water quality index result values and categorization for each year are given in Fig. 7. Both indexes primarily depend on bacteriological parameters (T-Coli, F-Strp and E-Coli) and oxygen indicators (BOD and DO). These parameters were below the limits; thus, the water quality class was found to be very low for the whole period analyzed, and it was not possible to determine conclusively whether or not the dam had an impact.

UWQI method uses nine parameters (As, BOD, Cd, DO, Hg, NO3, pH, PO4, and T_Coli). As, BOD, Cd, DO, NO3 and T-Coli parameters are seen as the most important parameters affecting the water quality. This index suggested that the water quality improved after the dam construction (Fig. 7).

OWQI method uses eight parameters (BOD, DO, E-Coli, F-Strp, Ammonia+Nitrate Nitrogen, pH, PO4 and TDS). BOD, DO, E-Coli, F-Strp, Ammonia+Nitrate Nitrogen and pH are the most important parameters that reduce water quality. The water quality categorization was found to be "very poor" for all years. This analysis did not lead to a certain statement whether the dam had an effect on the water quality or not (Fig. 7).

ATI method uses 13 parameters: DO, pH, Mn, Ni, Cr, Pb, NH4, Cu, Zn, PO4, K, Turbidity and TDS. The results give an idea of the suitability of water quality for aquatic life. One of the most important parameters is PO4, due to eutrophication. According to the ATI water quality index method, the water quality categorization was found as "Suitable for all fish life," and the dam had no impact (Fig. 7).

ATI and CCME-WQI methods are found to be more appropriate for the 10-year water quality assessment of the

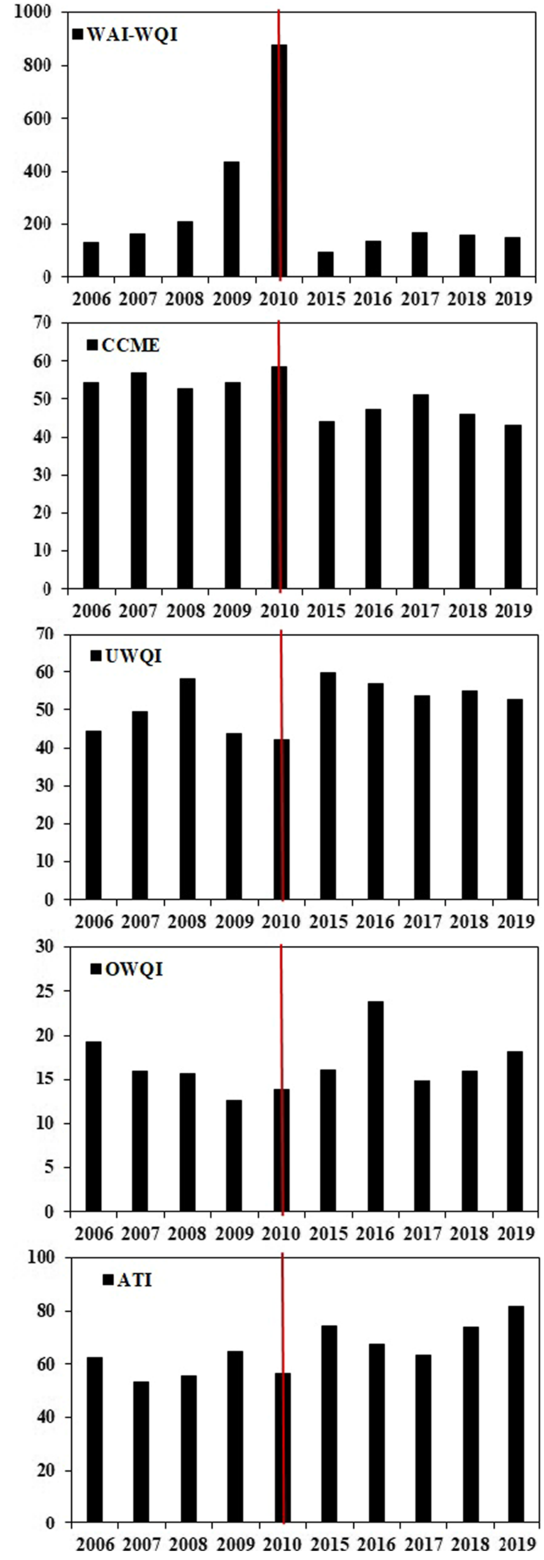

Fig. 7 Summary of water quality index model results (Dam construction year is 2010 represented with the red line)

Table 8 Sub-index and water quality index values before and after the construction of the Çine Dam in 2010, estimated by WAI-WQI, CCME-WQI, UWQI, OWQI and ATI Methods. No data are available between 2010 and 2015

Years	WAI	Class	CCME	Class	UWQI	Class	OWQI	Class	ATI	Class
2006	129.3	Unsuitable for drinking and fish culture	52.6	Marginal	44.2	Marginal	19.2	Very poor	62.5	Suitable for all fish life
2007	160.4	Unsuitable for drinking and fish culture	48.9	Marginal	49.6	Marginal	16	Very poor	53.1	Suitable only for hardly fish species
2008	209.3	Unsuitable for drinking and fish culture	38.8	Poor	58.1	Fair	15.6	Very poor	55.7	Suitable only for hardly fish species
2009	438.3	Unsuitable for drinking and fish culture	37.2	Poor	43.8	Marginal	12.5	Very poor	64.5	Suitable for all fish life
2010	878.7	Unsuitable for drinking and fish culture	34.5	Poor	42.1	Marginal	13.8	Very poor	56.7	Suitable only for hardly fish species
2015	91.5	Very poor	66.4	Fair	59.9	Fair	16.1	Very poor	74.3	Suitable for all fish life
2016	135.4	Unsuitable for drinking and fish culture	47.6	Marginal	56.7	Fair	23.8	Very poor	67.4	Suitable for all fish life
2017	166	Unsuitable for drinking and fish culture	41	Poor	53.6	Fair	14.9	Very poor	63.6	Suitable for all fish life
2018	159	Unsuitable for drinking and fish culture	44	Poor	54.9	Fair	16	Very poor	74.1	Suitable for all fish life
2019	148.8	Unsuitable for drinking and fish culture	47.9	Marginal	52.9	Fair	18.2	Very poor	81.5	Suitable for all fish life

sampled station on Çine River, based on the parameters considered in the indexes. It was also observed that BOD, COD, Cl, Cu, DO, E-Coli, F-Strp, Mn, NO2, PO4, SO4, T-Coli and TDS parameters exceed the limit values given in the standards (EPA, 2009; TSE, 2005; WHO, 2009, 2011a, 2011b; Turkish Regulation, 2019) causing a reduction in the water quality index values Table 8.

Conclusion

This study presented a methodology to assess the impacts of construction and operation of Çine Dam, in Aydin, Turkey, on the river flow regimes, sedimentation and water quality of the downstream reach of B.Menderes River. The analysis utilized all the available data, including the daily data sets of inflows for the period between 2012 and 2016 at three gauging stations: Çine Çakırbeyli Bridge, Aydin Bridge and Koçarlı Bridge. It also included sediment data monitored monthly for the period 2006–2019 at Çine Çakırbeyli Bridge station, and physico-chemical and heavy metal parameters monitored at Koçarlı Bridge station for the period 2006–2010, representing conditions before the dam construction, and at Çine Çakırbeyli Bridge station (S2) for the period 2015–2019, representing conditions after the dam construction.

To evaluate the water quality of the Çine River before and after the dam operation, five different water quality index methods were compared: Weighted Arithmetic Index (WAI-WQI) Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI), Universal Water Quality Index (UWQI), Oregon Water Quality Index (OWQI) and Aquatic Toxicity Index (ATI) Key observations made based on the analysis are as follows:

1) At the Çine Çakırbeyli Bridge station, downstream of the dam, the monitored sediment flux decreased dramatically, since most incoming sediments were trapped within the reservoir. Monitored sediment flux mean values (discharge*sediment concentration) decreased from a mean of 17,064.6 m3/s *ppm before the construction to 1487.6 m3/s *ppm after the construction of Çine Dam.
2) After the dam construction, observed pH values significantly decreased according to the Mann–Whitney U test. A decrease in pH value (i.e., acidic water) also affected levels of sulfate (SO_4), nitrate (NO_3) and aluminum (Al).
3) There was an increase in the amount of ammonia (NH4) values in 2016 and 2017 and the increase of nitrite (NO_2) in 2017 and 2018, suggesting a more intense discharge of domestic and industrial waste into the stream in these years.
4) Although phosphate (PO_4) values remained below the limits for the evaluation period, a significant peak was observed in 2010 immediately after the construction, suggesting that chemical–structural material had been deposited in the downstream. After year 2010, the suspended sediment concentration and the phosphate amount in the Çine River decreased due to the sediments trapped within the reservoir.
5) Construction of the dam decreased electrical conductivity (EC), which is a measure of the salinity of the water and the total dissolved solids (TDS). After the dam operation, their annual values remained below the standard limits.
6) BOD and COD values originating from domestic wastewater occasionally increased over the years due to the excessive agricultural practices in the basin and the settlements. The dam construction had no significant impact on these.
7) Calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K), indicators for the total hardness of the water, exceeded the limit values multiple times before the dam operation, yet remained below the limit values after the construction.
8) It is observed that peaks in zinc (Zn) values and in turbidity in 2010, immediately after the dam construction, attributed once again to the chemical–structural material released downstream during the construction.
9) Observed high values for the bacteriological parameters (E-Coli, F-Strp, and Total Coli) suggested that the Çine River waters were not suited to untreated discharges. Any discharge of agricultural and industrial waste into the surface water should be avoided.
10) ATI and CCME-WQI methods were found to be more appropriate for the 10-year water quality assessment of the sampled station on Çine River based on the parameters considered in the indexes. Significant change in ATI values is related to decreased phosphate (PO_4) values, which support the reduction of eutrophication observed at the river before the dam construction.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13762-021-03886-y.

Acknowledgements The authors would like to thank the DSI (General Directorate of State Hydraulic Works), Department of Survey, Planning, and Allocations, Environment Branch Directorate, Mrs. Sahra Koca, and the Deputy Director of DSI 21st Regional Directorate Mr. Nevzat Tatar for the providing of the data.

Funding None.

Data availability The data that support the findings of this study are available from [DSI (General Directorate of State Hydraulic Works), Department of Survey, Planning, and Allocations, Environment Branch Directorate] but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are, however, available from the authors upon reasonable request and with permission of [DSI (General Directorate of State Hydraulic Works)].

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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