

Evaluating the anthropogenic and geologic impacts on water quality of the Eğirdir Lake, Turkey

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Abstract Eğirdir Lake is the second largest fresh water lake with 482 km² surface area of Turkey. The lake is an indispensable water source for our country and region because of available water capacity and usage aims such as drinking-irrigation water, tourism, and fishing. However, especially contaminants located in the Eğirdir Lake catchment affect the lake water quality negatively in times. Therefore, determination of the water quality of the lake has quite importance for region human health and sustainable usage of the lake. The major factors that control the quality of the Eğirdir Lake water are agricultural activities in the basin, water–rock interaction, and domestic and industrial wastes. This study investigates the anthropogenic and geologic impact originated from pollution sources and water–rock interaction in the lake watershed basin to the Eğirdir Lake water quality. For this purpose, geological, hydrogeological, and hydrological properties of the lake basin with point and nonpoint pollution sources were investigated. To determine the water quality of the lake, 48 water samples were collected especially from locations representing effects of pollutants in May and October 2009. The analysis results were compared with maximum permissible limit values recommended by World Health Organization and Turkish drinking water standards. The contents of all chemical and physical parameters are

higher in dry periods than wet period, and water pollution was observed at discharge points of the streams into the lake. Also, pH, turbidity, potassium, chemical oxygen demand, ammonium, aluminum, iron, and lead concentrations were found to be above drinking water standards.

Keywords Water quality · Eğirdir Lake · Nutrients · Trace metals · Anthropogenic impact

Introduction

In the world, the water pollution has a great importance and the quality of surface and groundwater is very sensitive issue. But, pollution caused by human activities and natural processes reduces the available water resources. Pollutant species of agricultural and farming activities, untreated urban sewage and industrial effluents, driven into water bodies by wastewaters or surface runoff can be the cause of severe pollution (Campolo et al. 2002). Hence, investigation of the water quality has been the research subject of many researchers in various parts of the world (Tayfur et al. 2008; Umar and Ahmad 2000; Hu et al. 2005; Schoonover et al. 2005; Leung and Jiao 2006; Al-Khashman 2007; Kazi et al. 2009; Tabayashi and Yamamuro 2009; Fulazzaky et al. 2010; Najjar and Khan 2012). In addition, several studies can be seen about water quality assessment in the literature for 2012. Abdesselam et al. (2012) investigated anthropogenic contamination of groundwater in arid region and the study focused on nitrate contamination of groundwaters and its increase since the last 40 years. Wan et al. (2012) performed classification of rivers based on water quality assessment using factor analysis in Taizi River basin in China and all streams were divided into five classes marked (excellent, good, fair,

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poor, and seriously polluted) based on monitoring and analysis of the water quality parameters. Elçi and Selçuk (2012) determined effects of basin activities and land use on water quality trends in Tahtali Basin, Turkey. In the study, they revealed the importance of temporal and spatial remote sensing data to detect the changes in water quality as a result of human activities in the basin. Gemitzi (2012) investigated the long-term effects of human intervention on groundwaters based on the determination of natural background levels (NBLs) and threshold values (TVs) for groundwater electrical conductivity, chloride, ammonium, sulfates, and nitrates. Bozdağ and Göçmez (2012) assessed suitability of groundwater quality for drinking and agricultural purposes in the Cihanbeyli basin (Turkey) which was assessed by measuring physicochemical parameters, including major cation and anion compositions, pH, total dissolved solid, electrical conductivity, and total hardness.

Surface waters are more easily affected by pollution than groundwater and surface water quality in a region is largely determined both by natural processes (weathering and soil erosion) and by anthropogenic inputs (municipal and industrial wastewater discharge) (Kazi et al. 2009). In general, the chemical compositions of surface and groundwater are determined by a number of processes. However, surface water studies have received wide attention due to the need to understand the quality and chemistry of water, which is a cumulative reflection of the geology of the catchment area, precipitation, weathering processes, and anthropogenic activities (Al-Khashman 2007; Giridharan et al. 2010).

Surface water pollution is identified as the major problem affecting the Lake District in Turkey. Turkey's Lake District consisting of four large lakes (Beyşehir, Eğirdir, Burdur, Akşehir) and several smaller ones. In recent years, water levels of the lakes are decreased due to aridity and less rainfall in Turkey. In addition, the anthropogenic inputs negatively affect the lakes water quality. Eğirdir Lake is one of the most important freshwater lakes of the Turkey which is located within the Lake District. Some studies had been made related with the water level change, quality, and water products of the Eğirdir Lake (Ugurlu et al. 1999; Kesici and Kesici 2006; Bostancı et al. 2007; Güneş 2008). In addition, the major and trace elements in sediments of the lake had been determined by Alemdarolu et al. (2000). In literature, there is limited information on the effect of different anthropogenic activities and also geologic properties on the water quality of the Eğirdir Lake.

The main objectives of the present study are (1) to determine geological, hydrogeological and hydrological properties of the lake basin, (2) to define point and non-point pollution sources in the lake basin, (3) to assess the status of water quality with spatial changes for the Eğirdir Lake and to identify the most polluted parameters and their probable reasons, (4) to define temporal variation of the

lake water quality, and (5) to propose solutions for the local authority.

Description of Eğirdir Lake

The Eğirdir Lake is located within the Lake District at latitude $37^{\circ}50'41''$ – $38^{\circ}16'55''$ N, longitude $30^{\circ}57'43''$ – $30^{\circ}44'39''$ E in southwest Turkey (Fig. 1). The Eğirdir Lake having 4×10^9 m³ water volume is one of the most important fresh water lakes in Turkey and covers a lake area of 457 km². The Eğirdir Lake is a tectonic lake that lies in the north–south direction and was formed depending on rift tectonics (Koçyiğit 1983). The length of the lake is 50 km, the coastal length is 150 km, maximum width is 16 km, minimum width is 3 km, maximum depth of the lake is 13–14 m, and average depth is between 8 and 9 m. The altitude of the lake is approximately 918.96 m above sea level. The lake is an indispensable water source for our country and region because of the usage for different purposes such as irrigation, tourism, fishery, and also the drinking water supplied to Isparta city and neighboring settlements.

Geology–hydrogeology

The Eğirdir Lake catchment area covers an area of 3,390 km² and there are several geological units having different ages and lithologies in the study area (Fig. 2). Metamorphic units are the oldest rock units in the study area. Mesozoic-aged flysch overlies on the metamorphic units as unconformably. Autochthonous carbonate rocks are located in large scale in east and west of the lake. Ophiolitic complex is allochthonous unit and it overlies carbonates unconformably. The complex consists of diabase, sandstone, mudstone, limestone, radiolarian, and cherts. Paleogene-aged clastics overlies on the ophiolitic units in the west of the research area. This unit consists of sandstone, claystone, siltstone, and conglomerates, namely flysch. Also, Neogene-aged clastic and volcanic units are located in the basin. Clastic units crop out in the east of the basin, namely Neogene deposits. Volcanic units are located in the west of the lake and overlie carbonates and flysch unconformably. Quaternary deposits are composed of materials such as clay, silt, sand, and gravel, unconformably covering all of the other lithological units (Şener 2010).

According to hydrogeological investigations, the Eğirdir lake catchment area had researched as three groundwater sub-basins (Soyaslan 2004; Seyman 2005; Tay 2005). Senirkent-Uluborlu basin is located in the west of the lake, Yalvaç-Gelendost basin is located in the east of the lake, and Hoyran basin is also located in the northeast of the lake. The Quaternary alluvium and the Mesozoic carbonate rocks are classified as aquifer units in the basin. Alluvium

Fig. 1 Location map of the study area

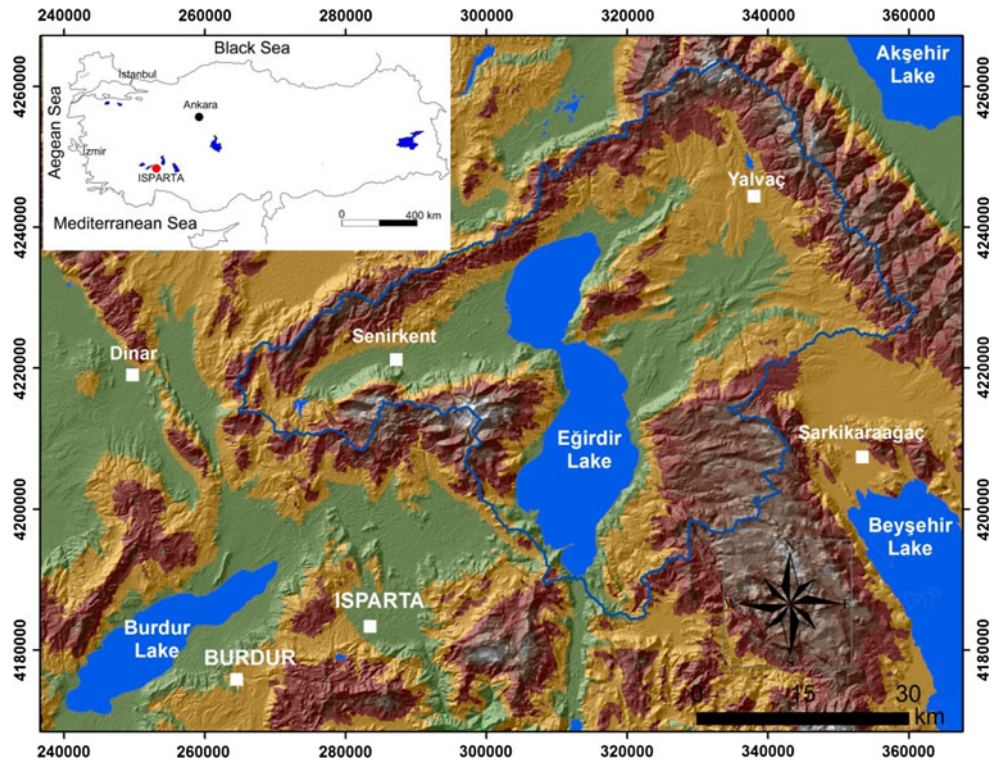
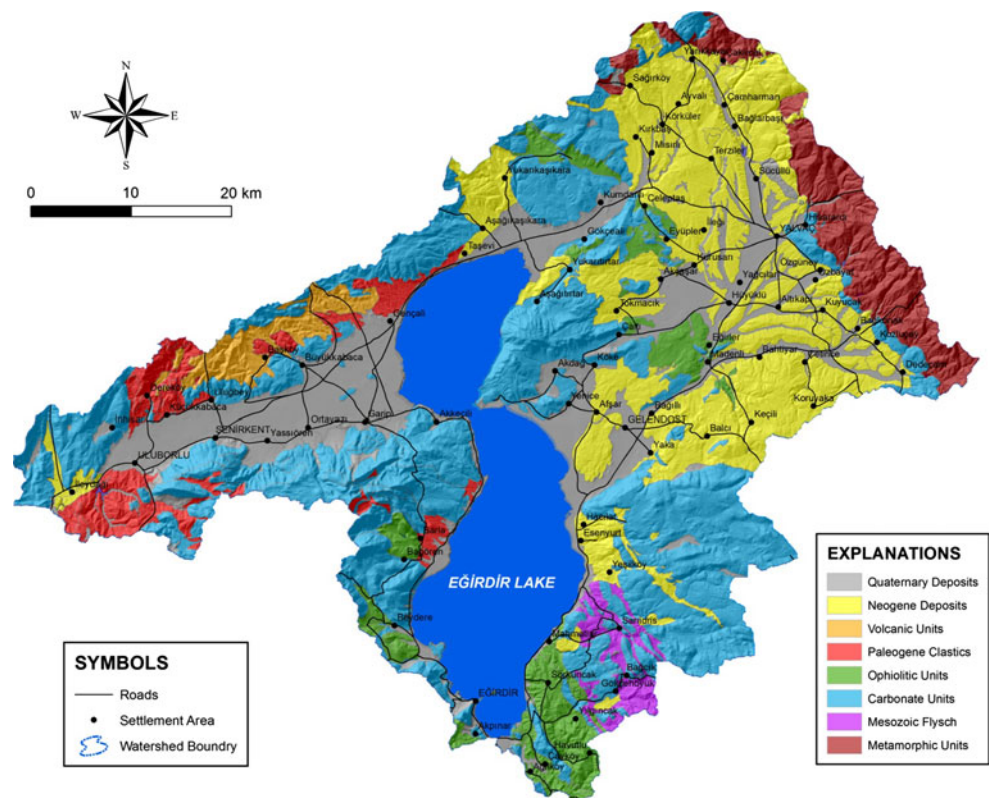


Fig. 2 Geological map of the lake basin



is the most important aquifer due to the porous structures and it covers an area of 525 km² in the basin. The groundwater depth is 3–36 m in the Senirkent-Uluborlu basin, 0.15–51.2 m in the Yalvaç-Gelendost basin, and

2.6–38.7 m in the Hoyran basin. The groundwater flow direction of the alluvium aquifer is toward the Eğirdir Lake in the lake catchment basin. In the west of the lake, the discharge amount of groundwater from alluvium aquifer

was calculated as 7.8 hm³/year (Seyman 2005). Limestone and dolomites which have aquifer properties have high permeability due to the presence of fractures and karstic holes. In the east of the lake, the amount of groundwater discharge to the Eğirdir Lake by means of the karstic aquifer was determined as 114 hm³/year using the MOD-FLOW model (Soyaslan 2004).

Hydrology

The maximum water level of the Eğırdir Lake is 918.96 m (Anonymous 2002). The lake is recharged by precipitation, surface flow, and groundwater flow from the Uluborlu-Senirkent and Yalvaç-Gelendost basins. The important surface waters flowing to the lake are Pupa Stream, Hoyran Stream, Yalvaç Stream, and Çay Stream which discharge 4.68, 3.42, 26.38 and 18.63 m³/s, respectively (Şener 2010). According to annual rainfall data obtained from the State Meteorology Works, the rainfall varies 348–788 mm in the lake basin. The lake discharged by means of evaporation, intake of irrigation and drinking water and flow to the Kovada canal. There are also water losses from karstic sinkholes at the western border of the lake (Davraz et al. 2009). The average rainfall in the basin for 62 years is 581 mm, the average temperature in the basin is 12 °C, the average humidity in the basin is 61 %, and the average annual evaporation in the lake is 1,221.9 mm (Güneş et al. 2001).

Pollutant sources

Generally, most human activities affect water quality, directly through the discharge of sewage and other wastewater or indirectly through landuse changes. In the basin, pollutant sources can be grouped into point and nonpoint sources. Domestic wastewater, constructed wetlands, uncontrolled landfills, and industrial activities are point pollution sources, and the most important nonpoint pollution is agricultural activities in the study area. Pollutants are transported into the lake via four main streams named as Pupa, Yalvaç, Hoyran, and Çay streams within the basin. Pupa Stream is the most important surface water in the west of the lake and transports wastewater of the Senirkent, Uluborlu, Büyük Kabaca, Küçük Kabaca, Uluğbey, Yasıören, Dereköy, and Ortayazı settlements to the lake. The Yalvaç Stream is second one, transports wastewater of the Yalvaç, Gelendost, and other neighboring settlements to the lake and discharges into the lake with two distributaries. Its discharge point is in the east of the lake. The wastewater from Kumdanlı and other neighboring settlements is discharged into Hoyran Stream and transported to the lake. Its discharge point is in the north of the lake. Also, Çay Stream transports wastewater of settlements located in the south of the basin and discharges south of the lake.

Point pollution sources

Domestic wastewater

There are 81 settlements in the basin, and the total population of these settlements is calculated as 122,702 according to population data of 2008. The Eğırdir and Yalvaç districts, the greatest districts in the basin, have wastewater treatment plants. The purified wastewater of the Eğırdir treatment plant is discharged into the Kovada channel; furthermore, the excess water of the Eğırdir Lake flows into the Kovada Lake. Also, the purified wastewater of the Yalvaç treatment plant discharges into the Yalvaç stream, and this stream flows into the Eğırdir Lake. The wastewater belonging to other settlements discharges into streams or into septic tanks and the streams flow into the lake, too. In the lake basin, groundwater contamination is inevitable due to wastewater collecting in septic tanks. Hence, septic tanks are potential pollution for the lake waters because of groundwater flow direction towards the lake. Even if wastewater treatment plants of the Yalvaç and Eğırdir districts are working with full capacity, 3,811,549 l/day of wastewater reaches the Eğırdir Lake either directly or indirectly from other settlements outside the scope of the facilities (Şener 2010). An important part of the wastewater that originates from other settlements comes from scattered areas that are far from the lake, and as a result, they are not directly discharged into the lake. In periods of heavy rain, there is runoff input into the lake through small streams and channels from these scattered areas. It is accepted that 80 % of the nutrients that originate from this runoff and domestic wastewater is transported to the lake via the streams (Güneş 2008).

Constructed wetlands

Constructed wetlands are natural wastewater treatment systems which are used for accumulating domestic and industrial wastewaters. Although constructed wetlands are viewed as simple treatment systems, complex and integrated interactions exist among microorganisms, fauna, flora, and surrounding ecologic compartments including the water itself (Çiftçi et al. 2007). There are nine constructed wetlands (in Senirkent, Uluborlu, Yalvaç, Gelendost and Eğırdir districts) in the basin and they can be described as pollutant sources at present. As their capacity is not enough for treatment, they affect surface and groundwater quality negatively.

Uncontrolled landfills

Solid wastes that are generated from industrial organizations and urban areas create serious environmental

problems (Chaulya 2003). There is no controlled landfill site in the basin and open dump areas located in the permeable units such as limestone and alluvium. The leachate generating from the open dump areas mixes into surface or groundwater. Hydrogeological data show the surface and groundwater flows toward the Eğirdir Lake in the basin. For this reason, all the contamination is transported to the lake via groundwater and surface water flows.

Industrial activities

Yalvaç Leather Tanneries located in the Yalvaç district are the main industrial pollutant within the basin. The wastewater of the 62 enterprises belonging to the tanneries is purified in the Yalvaç treatment plant. But, heaps of times these wastewaters directly flow into the Yalvaç Stream and its drainage canal, and reach lake directly through the Yalvaç Stream. The pollutant loads of Yalvaç treatment plant wastewaters are determined as 350–2,500 mg/l for BOD, 900–10,000 mg/l for COD, 10–250 mg/l for total Cr, 400–3,900 mg/l for suspended solids, and 0.2–150 mg/l for sulfur (Anonymous 1999). Sulfur, organic substances, and heavy metals such as chromium and zinc concentrations are expected to increase in surface and groundwater mixing of leather industry wastewater. In addition, Asya Fruit Juice Factory is located out of the basin. During the production facility, 1,600 m³/day of wastewater is composed and purified in the Eğirdir treatment plant. But, sometimes these wastewaters mix to the lake water due to working problems of treatment plants (Anonymous 1999). The pollutant loads of Asya Fruit Juice Factory wastewaters are included as 310 mg/l for BOD, 570 mg/l for COD, 200 mg/l for suspended solids and 6 for pH (Anonymous 1999).

Nonpoint pollution sources

Agricultural activities

Agricultural activities are the most important nonpoint pollution sources observed in the basin. The most intensive crop species are apple, cherry, apricot, and grape. In the basin, landuse types are divided into seven groups such as not irrigated arable land, irrigated arable land, orchards, pasture, forest, heathland, and bare rock; spatial distributions are given in Table 1. Not irrigated arable lands are the most common type of land use within the basin with a rate of 27 %. Apple, cherry, and other fruit farming are carried out in areas that are located at the sideline of the lake and near the other surface waters in the basin. During these activities, fertilizers (synthetic and natural) and pesticides are used extensively to increase product quality and quantity. The farmyard manure is used more intensively than synthetic fertilizer with 95,000 tons annual amounts.

Table 1 Spatial distributions of landuse types in the basin

Landuse types	Area	
	ha	%
Not irrigated arable land	80,809.137	27.19
Irrigated arable land	16,816.599	5.66
Orchards	18,192.249	6.12
Pasture	36,548.085	12.3
Forest	31,655.318	10.67
Heathland	45,075.608	15.16
Bare rock	68,120.057	22.92

Also, the annual amounts of nitrogen (pure N), phosphor (P₂O₅), and potassium (K₂O) are 2,591, 2,002, and 343 t, respectively (Anonymous 1999).

Methodology

Sample collection

Lake water samples were collected seasonal (dry—October 2009 and wet—May 2009) from 48 sites of the lake in accordance with United State Environmental Protection Agency methodologies (USEPA 2000). Water samples were collected from approximately 50 cm below surface of the lake water and the coordinates of these locations are loaded in the Magellan Explorist 600 manual Global Position System (GPS). While 1-l polyethylene bottles were used for collecting water samples, 500-ml dark-colored polyethylene bottles were selected for samples for analysis of BOD. During sampling, bottles labeled to avoid misidentification were rinsed in clear spring water several times and then filled to the top to minimize the entrapment of air in water samples (Larsen et al. 2001), and stored at 4 °C in the refrigerator. Sample preservation was accomplished by adding a hydrochloric acid as preservative to adjust pH. Preservatives were added to the container immediately after collecting the samples. Preserving samples in this way retards biodegradation, hydrolysis, precipitation, and sorption reactions (Tayfur et al. 2008).

Analytical procedure

Physical properties of the water samples such as pH, temperature (T; °C), electrical conductivity (EC; µS/cm), and dissolved oxygen (DO; mg/l) were measured in situ with YSI Professional Plus handheld multiparameter instrument that were calibrated with standard solutions. The major chemical constituents were analyzed at the ACME Laboratory (Canada-ISO 9002 Accredited Co.). The major cation and trace metal amounts were determined

by inductively coupled plasma mass spectrometry (ICP-MS) within group 2C-MS in ACME Laboratory, too. The turbidity of the samples was measured by Hach Turbidimeter. The Argentometric method based on titration of a sample with silver nitrate was used for the determination of chloride (AWWA 1995). The hydroxyl, carbonate, and bicarbonate concentrations were determined by titrimetric method. Spectrophotometer reagents and WTW photoLab Spectral-12 Spectrophotometer were used for the determination of COD, phosphate, total phosphorus, nitrite, nitrate, and ammonia. The WTW Oxitop IS 6 Inductive Stirring System was used for the determination of the BOD. SO_4 was determined spectrophotometrically by barium sulfate turbidity method (Clesceri et al. 1998; AOAC 1995). All of the analyses except for major cation and trace metal were performed in the Eğirdir Fisheries Research Institute Laboratory (Isparta/Turkey).

Mapping

The distribution maps of the water quality parameters were prepared by using Geographic Information System (GIS) techniques. ArcGIS software, Spatial Analyst extension, and IDW (Inverse Distance Weight) interpolation methods were applied in the study. IDW is the most suitable in the formulation of the interpolation of isodynamic contours. It also produces smooth and continuous surface changes between observations (Mantzafleri 2007).

Results and discussions

The basic statistical summary of the results of analysis belongs to physical and chemical parameters of water samples presented in Table 2. Also, the results are compared to the values of World Health recommended maximum permissible limits (WHO 2004) and TS 266 (Turkish Standards (TS) 2005).

Physical parameters

Water temperature influences the chemical and biological activity besides the growth of aquatic organisms (Pawar 2010). The in situ measured temperature values of the water samples ranged from a minimum of 20.8 °C in the wet period to a maximum of 28.9 °C in dry periods. The spatial distribution of the lake water temperature can be seen in Fig. 3a. The temperatures of the lake water samples were mainly changed with the lake water depth. It is highest in the north of the lake due to the low water depth.

According to TS 266 (TS 2005) and WHO (2004) standards, pH values for using as drinking water must be

between 6.5 and 8.5. pH varies significantly among the sampling sites with a range of 8.67–9.40 in the wet period and 8.75–9.48 in dry period. pH values of the lake water are represented as alkaline medium, and high pH values are measured in areas in which carbonate rocks interacted with water body (Fig. 3b). Therefore, high pH value is dependent on hydrogeochemical properties of the lake basin. pH range between 6.0 and 8.5 indicates the productive nature of water body (Garg et al. 2010). In general, pH values of the samples are over the eutrophication control limit values (pH: 8.5 max) according to Water Pollution and Control Regulations in Turkey (Anonymous 1998).

Wet and dry period EC values were between 331 and 465 $\mu\text{S}/\text{cm}$ and 363 and 505 $\mu\text{S}/\text{cm}$, respectively. The EC values of water samples are high in north and south of the lake (Fig. 3c). In north of the lake, effect of temperature is more dominant due to low lake water level. The increase in ion content originated from agricultural activities on the lake shore and settlement areas is also more dominant at the south of the lake.

The in situ measured dissolved oxygen (DO) values of the water samples ranged between 3.1 and 11.15 mg/l in the wet period, 5.38 and 11.98 mg/l in dry period. The DO values did not display differences between sampling periods. The north and southwest of the lake have low DO values (Fig. 3d) and these values are below the eutrophication control limit values (DO: minimum 7.5 mg/l) according to Water Pollution and Control Regulations in Turkey (Anonymous 1998). Turbidity values of the water samples ranged from 0.37 to 14.20 JTU in sampling periods. The highest value which is above the permissible limits (12.5 JTU) of turbidity was recorded at the sampling site 4 which is discharge point of the Pupa Stream into the lake.

Water type

To determine water type of the Eğirdir lake, major ion concentrations of the water samples are evaluated using the AquaChem 3.7 computer code. In general, all of the major ion concentrations were higher in dry period than wet period. Calcium concentrations were determined between 5.06 and 43.66 mg/l in dry period accordance with the standard limits. The range of sodium and magnesium were found in all the sampling sites as 4.85–13.47 mg/l and 18–44.98 mg/l, respectively within the standards limits, too. Although potassium concentrations of the water samples were about 1–3.5 mg/l, it was measured at sampling site 37 as 59.13 mg/l which exceeded the WHO limit. This location is near to orchards in the lake shore. Bicarbonate and carbonate values in water samples ranged from 173.85 to 345.80 and from 11.3 to 29.40 in the dry period, respectively.

Table 2 Physical and chemical parameters of the lake water

Parameters	Periods	Minimum	Maximum	Mean	Standard deviation	TS 266 limits	WHO limits
EC ($\mu\text{S/cm}$)	Dry	363.23	504.63	434.42	36.33	2,500 mS/cm	
	Wet	331	465	390.9	32.7		
PH	Dry	8.75	9.48	9.07	0.19	6.5–9.5	6.5–8.5
	Wet	0.36	9.4	8.8	1.26		
Temperature ($^{\circ}\text{C}$)	Dry	21.89	28.94	26.32	1.59		
	Wet	20.8	27.7	26.16	1.55		
DO	Dry	5.38	11.98	8.55	1.53		
	Wet	3.1	11.15	7.53	2.44		
HCO_3^{-2} (mg/l)	Dry	173.85	345.8	232.67	29.53		125–350
	Wet	152.5	251.32	210.15	21.72		
CO_3^{-2} (mg/l)	Dry	11.3	29.4	19.98	4.23		
	Wet	9	27	17.1	4.45		
Cl^{-} (mg/l)	Dry	9.72	17.95	13.28	1.96		
	Wet	7.09	15.96	10.26	1.59	250	250
SO_3^{-2} (mg/l)	Dry	23.4	63.78	40.76	10.38		
	Wet	20.16	61.32	37.9	10.30	250	250
Na (ppm)	Dry	4.85	13.47	10.21	2.10		
	Wet	4.52	12.28	9.47	1.91	200	200
Ca (ppm)	Dry	5.06	43.66	21.28	6.04		
	Wet	4.81	41	19.84	5.64	100	100
K (ppm)	Dry	0.96	59.13	3.6	8.21		
	Wet	0.87	54.45	3.32	7.56		20
Mg (ppm)	Dry	18	44.98	38.07	6.10		
	Wet	16.6	41.44	35.47	5.58		50
Turbidity (JTU)	Dry	0.54	14.2	1.72	2.01	12.5	
	Wet	0.37	13.6	1.46	1.95		
COD (mg/l)	Dry	9.44	27.4	16.32	3.17		
	Wet	7.6	24.1	13.87	3.03		10
BOD (mg/l)	Dry	0.3	5.8	0.90	0.85		
	Wet	0.2	4.7	0.63	0.72		6
NH_3^{+} (mg/l)	Dry	0.1	1.86	0.26	0.27		
	Wet	0.07	1.53	0.23	0.22		
NH_4^{+} (mg/l)	Dry	0	1.89	0.30	0.27		
	Wet	0.07	1.62	0.24	0.24	0.5	
NO_3^{-} (mg/l)	Dry	0.94	4.23	2.35	0.77		
	Wet	0.72	3.69	2.0	0.63	50	50
NO_2^{-} (mg/l)	Dry	0.023	0.08	0.04	0.01		
	Wet	0.019	0.07	0.03	0.01	0.5	3
Total organic carbon (mg/l)	Dry	16.12	39.35	28.06	4.90		
	Wet	13.59	37.29	25.51	4.76		
PO_4^{-3} (mg/l)	Dry	0.142	1.43	0.52	0.26		
	Wet	0.034	1.2	0.39	0.25		
Total Phosphor (mg/l)	Dry	0.12	1.29	0.35	0.24		
	Wet	0.09	1.25	0.25	0.21		
Al (ppm)	Dry	0.00439	0.29	0.03941	0.04780		
	Wet	0.004	0.264	0.03554	0.04327	0.2	0.2
Co (ppm)	Dry	0.00005	0.0005	0.00014	0.00008		
	Wet	0.00004	0.00044	0.00012	0.00007		0.04

Table 2 continued

Parameters	Periods	Minimum	Maximum	Mean	Standard deviation	TS 266 limits	WHO limits
Cu (ppm)	Dry	0.00022	0.00257	0.00092	0.00052		
	Wet	0.0002	0.0023	0.00084	0.00048	2	2
Fe (ppm)	Dry	0.00987	0.40794	0.04810	0.06759		
	Wet	0.009	0.372	0.04313	0.06113	0.2	0.3
Mn (ppm)	Dry	0.00094	0.022	0.00404	0.00407		
	Wet	0.00083	0.0198	0.00362	0.00365	0.05	0.1–0.5
Ni (ppm)	Dry	0.00055	0.00280	0.00111	0.00040		
	Wet	0.0005	0.0025	0.0010	0.00036	0.02	0.02
Pb (ppm)	Dry	0.00011	0.01313	0.00068	0.00191		
	Wet	0.0001	0.0117	0.00060	0.00170	0.01	0.01
Zn (ppm)	Dry	0.00044	0.01163	0.00186	0.00219		
	Wet	0.0004	0.0106	0.00167	0.00198		0.01

Anions such as chloride and sulfate are the major inorganic components deteriorating the quality of groundwater as drinking water. The range of chloride and sulfate were found in all the sampling sites as 9.72–17.95 and 23.4–63.78 mg/l, respectively. These values are suitable with the standards limits. However, the chloride and sulfate concentrations are increased at discharge points of streams and farming areas along the lake shore. This situation is represented as the effect of anthropogenic pollutants carried by streams and irrigation waters reaching the lake with subsurface flow from farming areas along the lake shore.

According to this analysis results, the general order of cations is $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ and the order of anions is $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{CO}_3^{2-} > \text{Cl}^-$. The Ca, Mg and HCO_3^- ions are dominant in the lake water, and the lake waters are generally Ca–Mg– HCO_3^- type. But, the different water types are shown such as Mg– HCO_3^- , Mg–Ca– HCO_3^- – SO_4 , Mg– HCO_3^- – SO_4 and Mg–K– HCO_3^- . The increase of Mg content is generally related to water–rock interaction with dolomitic rocks.

Nutrients in the lake water

Nutrients such as the bioavailable forms of phosphorus and inorganic nitrogen (ammonia, nitrate and nitrite) are important factors affecting lake water quality. The nutrient status of lakes is strongly related to their depth and the types of land use and human activities in the catchment. Nutrient loading is a function of both the availability of nutrients in a watershed and their potential for movement to receiving waters (Fraterrigo and Downing 2008). Phosphate (PO_4) enters the lakes with domestic wastewater, accounting for the accelerated eutrophication and the augmented concentration of PO_4 and $\text{NO}_3\text{-N}$ in lakes resulted in enhanced phytoplankton productivity (Pandit and Yousuf 2002; Vyas et al. 2006).

The ammonia (NH_3) values of the Eğirdir Lake water are between 0.1 and 1.86 mg/l in dry period and 0.07–1.53 mg/l in wet period. The ammonium (NH_4) values of the lake water are also between 0.07 and 1.89 mg/l, and these values exceeded the limits of Turkish Standards' proposed drinking water quality criteria. The highest value of ammonium was recorded at the sampling site 4 which is discharge point of the Pupa Stream into the lake. The range of nitrite (NO_2) and nitrate (NO_3) were found in all the sampling sites as 0.02–0.08 mg/l and 0.72–4.23 mg/l, respectively within the standards' limits. However, the maximum concentrations of the nitrogenous compounds are observed at the sampling sites which are discharge points to the lake of the streams (Fig. 4a). This shows that the nitrogenous compounds are important anthropogenic pollutant for the Eğirdir Lake and transport to the lake via streams. Also, NO_3 values were compared with temperature, pH, DO values in a scatter plots in Fig. 5a–c, respectively, and the correlation coefficients were given in Table 3. The results show that nitrate values have a very weak positive correlation with temperature, but very weak negative correlation with pH and DO values.

The maximum values of phosphate, total phosphorus, and total organic carbon (TOC) of the lake water were observed at the discharge points of the streams and around the Eğirdir district in the south of the lake. The phosphate and total phosphorus values are between 0.03 and 1.43 mg/l and 0.09 and 1.29 mg/l, respectively (Fig. 4b). Total phosphorus values of the samples are over the eutrophication control limit values (0.1 max) according to Water Pollution and Control Regulations in Turkey (Anonymous 1998). Also, TOC values of the lake water were measured between 13.59 and 39.35 mg/l. Although TOC concentrations in the middle of the lake were considerably low, it has higher concentrations in the lake shore (Fig. 4c). This situation is represented as the effect of domestic wastewaters,

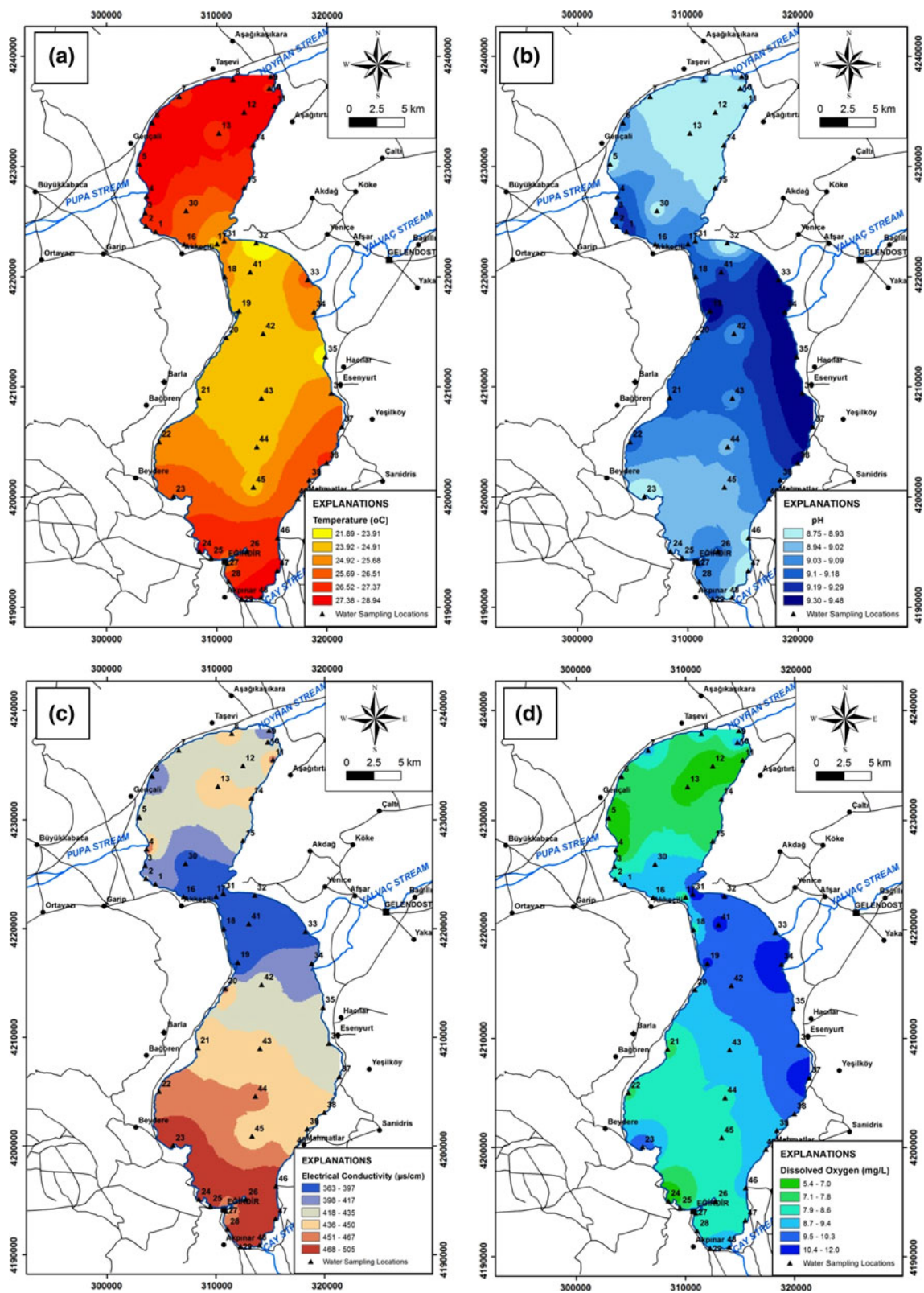


Fig. 3 The spatial distribution of temperature (a), pH (b), EC (c), and dissolved oxygen (d) in the lake

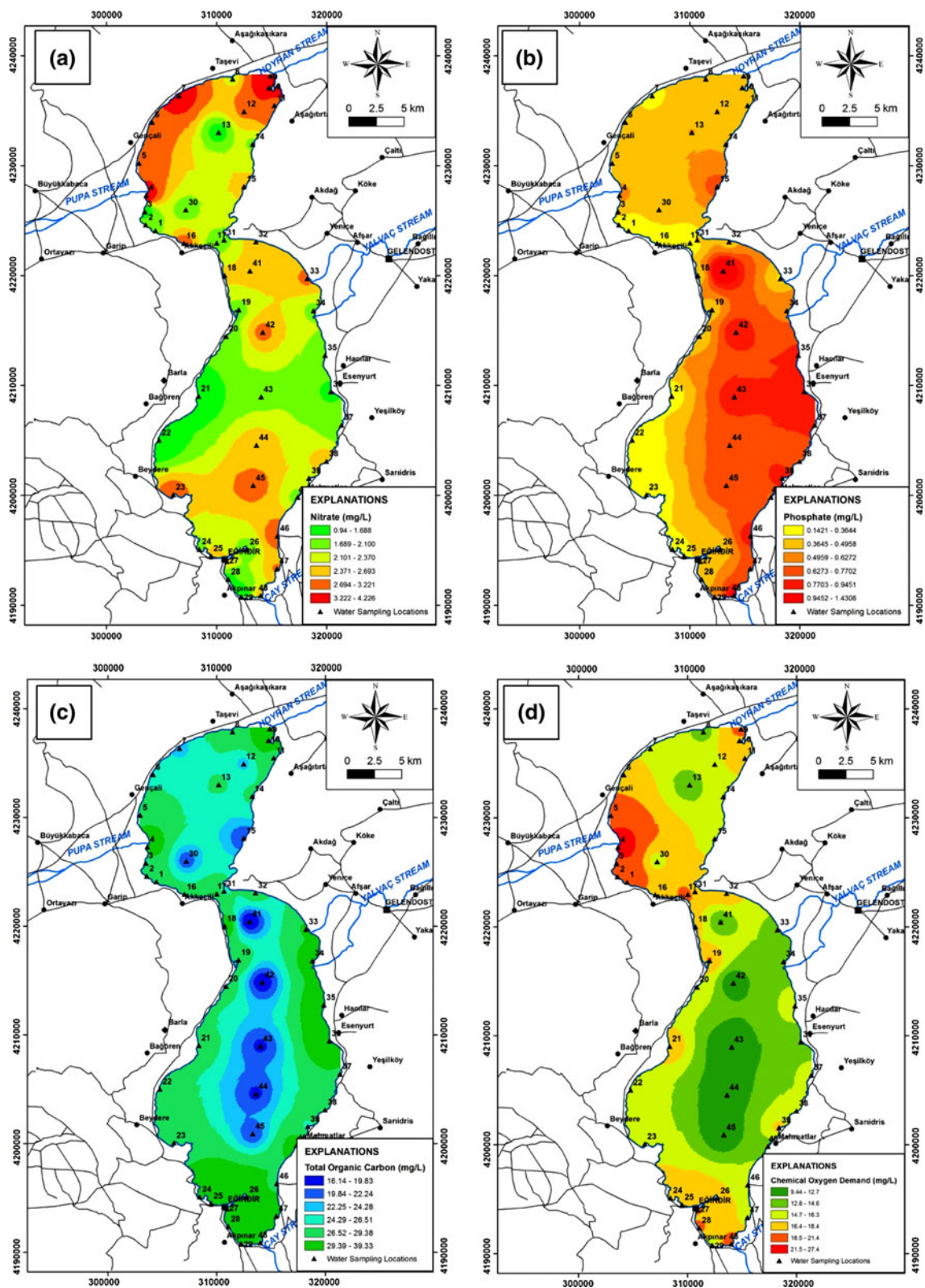


Fig. 4 The spatial distribution of nitrate (a), phosphate (b), TOC (c), and chemical oxygen demand (d) in the lake

fertilizers and pesticides using at agricultural activities. When the phosphate and TOC values were compared with temperature, pH, DO values; very weak negative

correlations were observed between phosphates: temperature and TOC values: DO (Fig. 5d, i; Table 3). The scatter plots show that phosphate and TOC values have weak

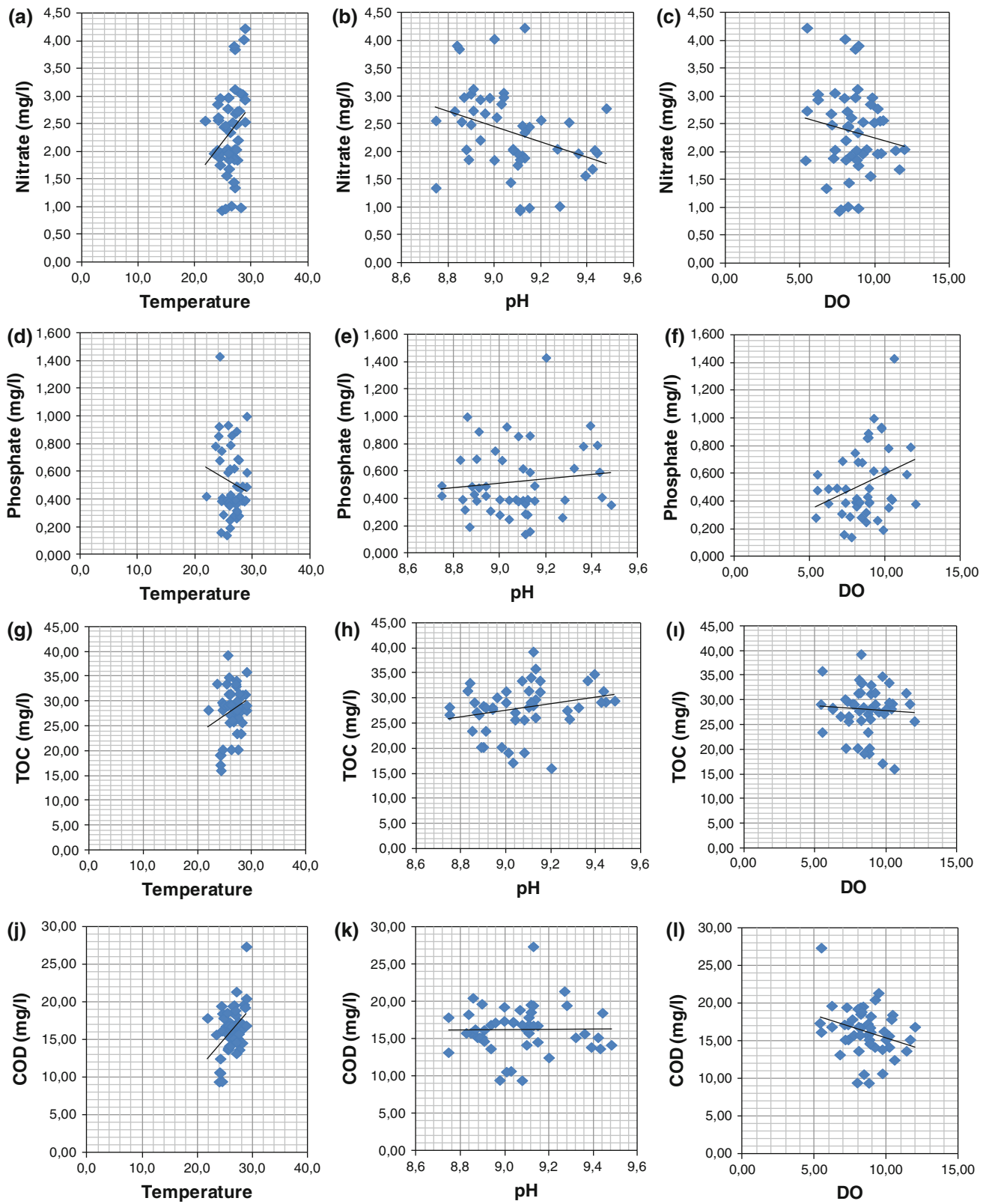


Fig. 5 Scatter plots of nitrate, phosphate, TOC and COD values against temperature, pH and DO

Table 3 Correlation coefficients between nutrient, trace-metal values and temperature, pH, DO values

	Temperature (°C)	pH	DO
Nitrate	0.08	-0.11*	-0.02
Phosphate	-0.02	0.01	0.10*
TOC	0.05	0.06	-0.004
COD	0.19*	0.0001	-0.08
Fe	-0.025	0.17*	0.09
Al	-0.01	0.19*	0.10
Pb	-0.002	0.07	0.11*

* $p < 0.05$

positive correlation with pH values in lake water (Fig 5e, h), TOC values have very weak positive correlation with temperature, and also phosphate values have very weak positive correlation with DO (Fig. 5g, f and Table 3).

The monitoring of oxygen concentration in aquatic system is an important subject (Galal-Gorchev et al. 1993), as the biological, chemical, and physical processes are involved in the increase or decrease of oxygen in the lake (Kazi et al. 2009). The chemical oxygen demand (COD) and biochemical oxygen demand (BOD) values are not homogeneous in the Eğirdir lake water like phosphate, total phosphor and TOC values. The COD and BOD values are between 7.6 and 27.4 and 0.2 and 5.8 mg/l, respectively. The highest value of COD was measured at the sampling site 4 which is discharge point of the Pupa Stream into the lake and the lake shore (Fig. 4d). The higher values of BOD were observed the sampling site 4 due to local anthropogenic pollution like COD. While, COD values have weak positive correlation with temperature, a very weak negative correlation was observed with DO values (Fig. 5j, l; Table 3). But, there is no any relationship between COD values and pH (Fig. 5k; Table 3).

Trace metals in lake water

Trace metals may be present in natural surface and groundwater, while the sources of these metals are associated with either natural processes or human activities (Al-Khashman 2007). The concentrations of the Al, Co, Cu, Fe, Mn, Ni, Pb and Zn of the lake water samples were analyzed to identify existing contaminants and the results are represented in Table 2. According to the analysis results, Co, Cu, Mn, Ni and Zn concentrations are found to be less than limits for drinking water of WHO (2004) and TS 266 (2005). However, concentrations of the Al, Fe and Pb are above the permissible limits. The spatial distribution of these metals can be seen in Fig. 6 a–c, respectively. The highest value of Al (0.29 mg/l) and Fe (0.4 mg/l) were

measured at the sampling site 35 which is located in the south of the Yalvaç Stream discharge point. Also, the highest value (0.013 mg/l) of Pb was recorded at the sampling site 35 and 37 sampling sites that tend to interact with the Neogene deposits which are composed of sandstone, claystone, siltstone, and limestone. These sampling points are also in contact with farming areas. The scatter plots of Fe, Al, Pb values against temperature, pH, and DO are presented in Fig. 7a–i, and correlation coefficients were given in Table 3. In general, Fe, Al, and Pb values showed very weak negative correlation with temperature and very weak positive correlation with pH and DO values.

The high trace-metal concentrations can be related to the water–rock interaction or pesticides that contain inorganic compounds such as Pb, Cu, Zn, As, and Hg. The distributions of the Co and Cu were not homogeneous in the lake water like as Mn and Ni. The highest value of Co (0.0004 mg/l), Cu (0.002 mg/l) and Ni (0.002 mg/l) were recorded at the sampling site 4 and 35 related to anthropogenic pollution and water–rock interaction. However, the highest Mn concentration (0.02 mg/l) was determined at sampling site 35 and 48. Sampling site of 48 interacts with the ophiolitic rock units that overlie the south of the lake. In this region, there is no anthropogenic effect related to Mn ion. Therefore, high Mn concentration is probably a result of the water–rock interaction with ophiolitic rock of the lake water.

The locations of the pollution sources and sampling sites are presented in Fig. 8. In addition, water quality parameters measured maximum values in water samples are indicated in the map. It is obviously shown that the most pollution load is observed at sampling site 4. In addition, nitrogenous and phosphor compounds are observed at the discharge points of the four main streams (sampling sites 4, 9, 33 and 48). To determine the relationship between farmland area ratio belonging to sub-watersheds in the study area and contents of the nitrogenous and phosphor compounds, the scatter plots were prepared (Fig. 9a–c). The farmland area ratio of the sub-watersheds was calculated using ArcGIS software. Also, TOC, ammonia, and phosphate values used in scatter plots are average values of the sampling locations that may be influenced by farmland areas. According to obtained results, there is tendency for water quality species to increase as farmland area ratio goes up. This supports that as a result of agricultural activity in the lake basin, the concentrations of the nitrogenous and phosphor compounds increase in the lake water. Especially, at sampling sites of 35 and 37, the increase of trace metals is based on agricultural pollution and water–rock interactions. The water–rock interaction related with ophiolitic units can be seen obviously in the south of the lake, at sampling site 48.

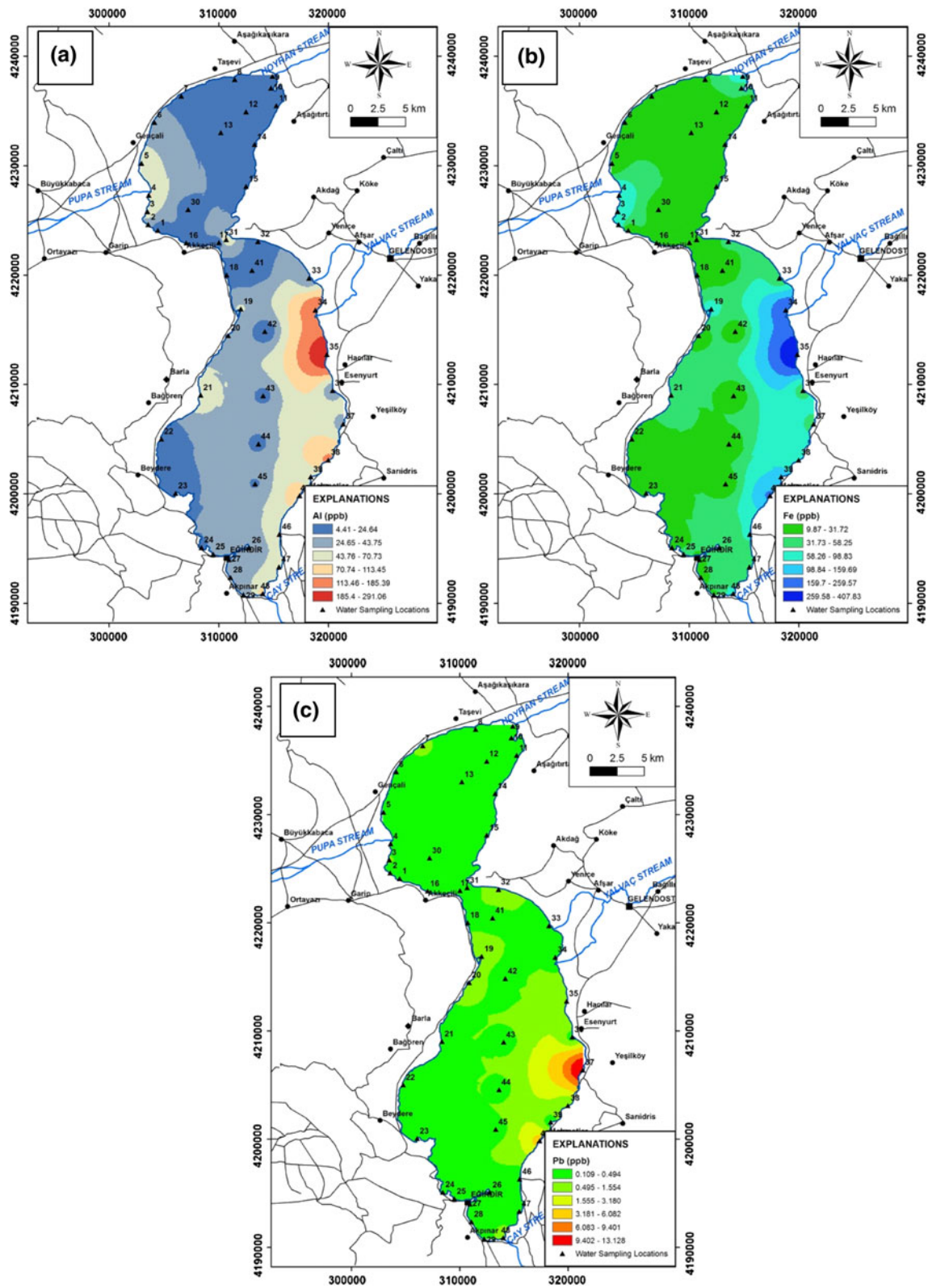


Fig. 6 The spatial distribution of Al (a), Fe (b), Pb (c) in the lake

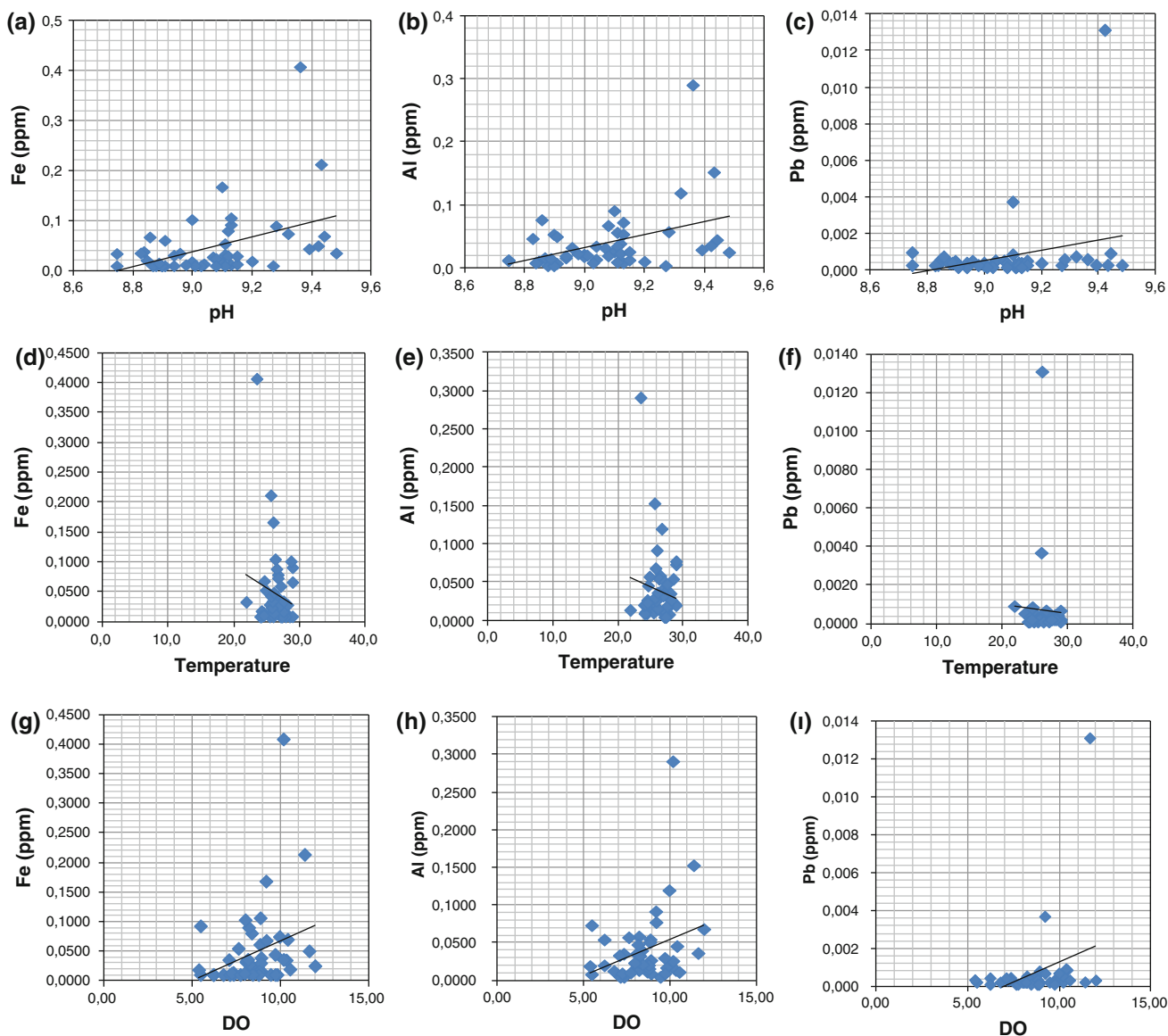


Fig. 7 Scatter plots of Fe, Al, Pb values against temperature, pH and DO

Temporal variation in the lake water quality

The presence of anthropogenic influence and the temporal variation of the lake water quality were investigated in comparison with previous studies. The first study was made by Nümann (1958) in the Eğirdir Lake. In this study, pH, dissolved oxygen, and total phosphor values of the lake water belonging to May 1953 and May 1954 were given. Gündüz (1984) examined contents of major anion, cation, and NO_3 of the lake water in the 1981, 1982, and 1983. The COD and total phosphor values of the lake water are studied by Günay et al. (1985). Trace metals and major ion contents of the lake are identified by Gölge et al. (1986). In 1986, the contents of major ion, NO_2 , NO_3 , and NH_3 of the lake water were again studied by Merter et al. (1986).

Finally, Aydın (1993) investigated EC, temperature, dissolved oxygen, PO_4 , NO_2 , NO_3 , and NH_3 parameters of the lake water at eleven locations.

On examining studies accomplishing in different years since 1953, there is not a striking change at the temperature and major ion contents of the lake water. When the K, COD, and EC values of the lake water regionally increased, dissolved oxygen values decreased. Although, phosphor ion is not determined in the lake water in 1953, it has increased continuously within the time, and eventually, the phosphor concentration (0.005–1.0 mg/l) is measured over of eutrophication control limit values (0.1 max) in 2009. This situation shows that the Eğirdir Lake is affected from anthropogenic pollutants. In addition, SO_4 and nitrogen concentrations of the lake water are also increased

Fig. 8 The general assessment of lake water quality and pollution sources locations

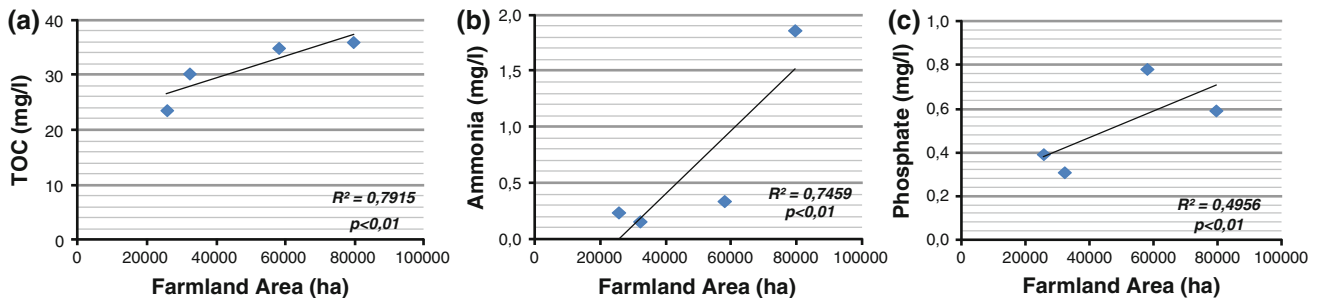
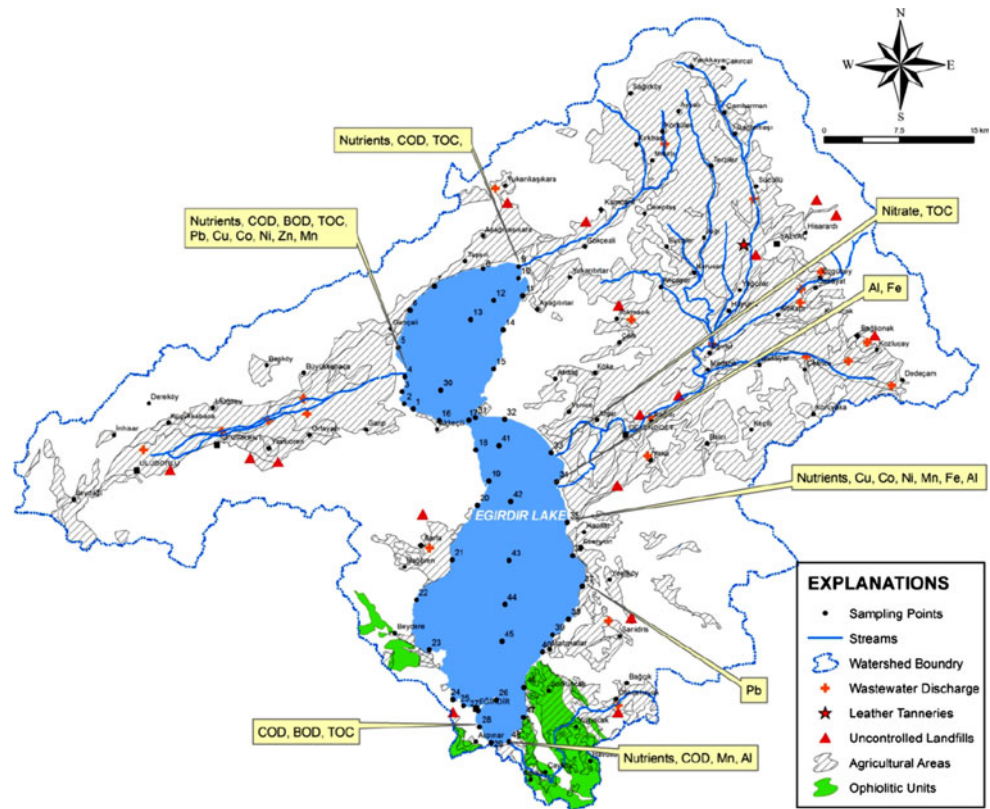


Fig. 9 Scatter plots of TOC, ammonia and phosphate values against farmland areas

depending on the time. These increases are related to agricultural activities showing a steady increase.

Nowadays, trace-metal contents of the lake water decreased when compared to the results of analyses which are determined in 1986. This decrease is observed in the lake water samples taking in Eğırdir district and surrounding. Because, waste waters of the Eğırdir district and factories in the surrounding are purified at Eğırdir treatment plant which is established in 1998, and purified waters are given into the lake.

Suggestions for local authority

To protect lake water quality and provide sustainable usage of the lake some suggestions were given for local authority.

Agricultural activities are the most important pollution sources in the basin and cause increase of nutrient and trace-metal pollution. To prevent the pollution, agricultural activities should be taken under the control in the basin. First, the education and awareness-raising activities of the farmers should be made by local administrators. The usage and appropriate dosage of the pesticide and fertilizer should be controlled by agricultural engineers. The most importantly, organic pesticides should be preferred instead of inorganic pesticides. At the same time, nutrient and trace metal pollution is of anthropogenic origin and could be due to domestic wastewater (seepage of water from septic tanks and direct discharge to the streams), constructed wetlands, uncontrolled landfills, and industrial activities in the basin. In 2007, constructed wetland project was drafted for the

Pupa stream and Gelendost drainage channel, which pollute Eğirdir Lake heavily and which transport 27 % of the domestic wastewater. If these projects were realized, the nitrogen and phosphorus discharge into the lake that originate from the wastewater management subsystem would be reduced to 147.5 and 143.4–130.2 t/year, respectively (Güneş 2008). But now, these constructed wetlands are not functional to prevent wastewater problem and there is a need regular treatment plant. In the basin, Yalvaç and Eğirdir districts have treatment plant but sometimes these plants cannot work functional due to some local problems (Anonymous 1999). This negative situation can be removed only by controlling the treatment plants. In addition, another treatment plant should be constructed in the Senirkent-Uluborlu basin to purify wastewaters of the settlements. To prevent negative effect of the uncontrolled landfills, waste management must be regulated in the basin. Finally, further research on health risk assessment studies may be made to confirm this outcome.

Conclusion

The Eğirdir Lake is the second largest fresh water lake of Turkey and it is used as drinking water in the region. In present study, anthropogenic and geologic impact on the Eğirdir Lake water quality was investigated with researches of geologic, hydrogeologic, hydrogeochemical, and pollution sources. First, geologic and hydrogeologic properties of the basin were determined beside point and non-point pollution sources. To present hydrogeochemical properties of the lake, 48 sampling sites were distributed within the lake and 30 water quality parameters were selected for seasonal monitoring and analysis. According to obtained results, the lake waters are dominantly characterized with Ca–Mg HCO₃ water type. Also, the main results of this study are indicated as follows.

- Lake water is adversely affected from the pollutants in the lake catchment area.
- Agricultural areas near to the lake are a serious risk for the lake water quality.
- An important part of pollution loads is transported into the lake via four main streams.
- The nutrient loads of the lake water are directly related with anthropogenic sources such as agricultural activities and wastewater discharge from especially streams.
- Total phosphor and pH values of the lake water samples are over the eutrophication control limit values according to Water Pollution and Control Regulations in Turkey.
- In general, trace-metal contents in the lake water samples were low, only Al, Fe, and Pb concentrations

were measured above the permissible limits at sampling sites of 35 and 37 related to agricultural pollution and water–rock interaction.

- Comparing the results of the current analysis of the lake with old data, nitrogen and phosphorus loads were increased as time-dependent.

This study shows that attempts at conservation and restoration of the lake require accurate understanding of the many environmental factors and hydrogeological properties of the watershed basin. Pollution effects of agricultural activities are the most common in the Eğirdir Lake watershed area and protection of lake water quality can be accomplished by controlling potential contaminant sources and by managing land use in catchment areas. The lake is an indispensable water source for our country and region. Therefore, the obtained results with this study should be taken into consideration and required preventions should be taken for sustainable usage of the lake.

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