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Araştırma Makalesi / Research Article

Water Quality Assessment of the Erfelek Dam Lake in the Context of Drinking Water Treatment Plant, Sinop Municipality, Northern Türkiye

Betül METE[1*], Gül Eda KARADENİZ[2], Adem BAYRAM[3]

Abstract

Domestic water demand for the city of Sinop has been supplied by the Erfelek Dam Lake on the Karasu Stream after treatment at the drinking water treatment plant of the Sinop Municipality, Türkiye. The aim of this study is to assess the dam lake water quality firstly with reference to seven parameters: water temperature, hydrogen ion concentration, dissolved oxygen concentration, electrical conductivity, turbidity, total iron, and manganese ion. It is to assess the suitability for human consumption lastly with reference to six more indicators: ammonium nitrogen, nitrite nitrogen, nitrate nitrogen, chlorine, residual chlorine, and copper ion. Daily water quality data was considered for two periods, each of which is one year. The quality assessment was performed according to the Turkish Surface Water Quality Regulation (TSWQR). The results for the untreated reservoir waters matched the permissible levels by the TSWQR. On the other hand, the after treatment water quality and safety of the reservoir waters matched the standards imposed by the Regulation Concerning Water Intended for Human Consumption. In addition, water quality index (WQI) values for the years 2014 and 2023 were calculated for the Erfelek Dam Lake, and the temporal change of the water quality was investigated. Calculated WQI values indicated a significant deterioration in the water quality of the Erfelek Dam Lake in 2023, particularly in the summer months, compared to 2014. With this study, the drinking water quality of Sinop Province is assessed for the first time.

Keywords: Drinking water, Karasu Stream, Sinop Province, Water quality index.

Sinop Belediyesi İçme Suyu Arıtma Tesisi Kapsamında Erfelek Baraj Gölü Su Kalitesinin Değerlendirilmesi

Öz

Sinop ili içme ve kullanma suyu ihtiyacı, Karasu Çayı üzerindeki Erfelek Baraj Gölü'nden temin edilen suların Sinop Belediyesi içme suyu arıtma tesisinde arıtılması ile karşılanmaktadır. Bu çalışmanın amacı su sıcaklığı, hidrojen iyonu konsantrasyonu, çözünmüş oksijen konsantrasyonu, elektriksel iletkenlik, bulanıklık, toplam demir ve mangan iyonu olmak üzere yedi göstergenin referans alınarak baraj gölü su kalitesinin değerlendirilmesidir. Ayrıca, içme amaçlı kullanılan sular için arıtma sonrası su kalitesi amonyum azotu, nitrit azotu, nitrat azotu, klor, bakiye klor ve bakır iyonu olmak üzere altı göstergeye göre daha değerlendirilmiştir. Her biri bir yıl olmak üzere iki dönem için günlük su kalitesi verileri incelenmiştir. Kalite değerlendirmesi Yerüstü Su Kalitesi Yönetmeliği'ne (YSKY) göre yapılmıştır. Arıtılmamış rezervuar suları için sonuçlar, YSKY tarafından izin verilen seviyelere uygun bulunmuştur. Diğer yandan, arıtma sonrası su kalitesi, İnsani Tüketim Amaçlı Sular Hakkında Yönetmelik'e uygun bulunmuştur. Erfelek Baraj Gölü için 2014 ve 2023 yılları su kalitesi indeks değerleri de hesaplanmış ve su kalitesinin zamana bağlı değişimi incelenmiştir. Erfelek Baraj Gölü su kalitesinde, özellikle de 2023 yılının yaz aylarında, 2014 yılına kıyasla önemli bir bozulma olduğu sonucuna varılmıştır. Sinop ilinin içme suyu kalitesi ilk kez bu çalışma ile değerlendirilmiştir.

Anahtar Kelimeler: İçme suyu, Karasu Çayı, Sinop İli, Su kalitesi indeksi.

[1]Karadeniz Technical University, Department of Civil Engineering, Trabzon, Türkiye, betulmete@ktu.edu.tr
[2]MS Süren İnşaat Sanayi ve Ticaret Limited Şirketi, Samsun, Türkiye, guledakaradeniz@gmail.com
[3]Karadeniz Technical University, Department of Civil Engineering, Trabzon, Türkiye, adembayram@gmail.com

[*]Sorumlu Yazar/Corresponding Author
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1. Introduction

Water is a vital and indispensable resource for all living things. Although about 75% of the Earth's surface is covered with water, usable freshwater only covers 2.5% of the total water resources. Approximately 69% of them are in ice and glaciers, and 30% are underground. Surface freshwater resources such as rivers and lakes account for about 1% of the world's total freshwater (Xiong et al., 2016). The pressure on existing water resources, which is caused of climate change, industrialization, urbanization and population growth, degrades natural ecosystems and reduces the availability of clean water for human consumption (Rijsberman, 2006; Kukrer and Mutlu, 2019). For this reason, sustainable management of existing freshwater resources, protection and improvement of water quality is of great importance.

The demand for water in cities is increasing day by day due to population growth and urbanization. Many resources are utilized to meet the demand for water. Dam reservoirs are one of the widely used surface fresh water resources for drinking and utility water supply (Park and Kim, 2003). After the required amount of water is taken from the dam reservoirs and subjected to the necessary treatment processes, it is transmitted to the settlements through transmission and distribution lines. To understand the water quality characteristics of the reservoirs, and to ensure the safety of regional drinking water, water should be examined in terms of physical, chemical and biological parameters (Lachhab et al., 2021). In Türkiye, the surface waters have been classified with reference to the Turkish Surface Water Quality Regulation (TSWQR) published in the Official Gazette dated 30.11.2012 and numbered 28483 (TSWQR, 2012) as well as amended in the Official Gazette dated 15.04.2015 and numbered 29327 (TSWQR, 2015). Their suitability for human consumption has been evaluated with reference to the Regulation Concerning Water Intended for Human Consumption (RCWIHC) published in the Official Gazette dated 17.02.2005 and numbered 25730 (RCWIHC, 2005) as well as amended in the Official Gazette dated 20.10.2016 and numbered 29863 (RCWIHC, 2016).

Satılmış (2015) investigated the spatial and temporal variation of surface water quality in the Galyan and Kuştul streams feeding the Atasu Dam Lake, which is used to meet the drinking water demand of Trabzon Province. Water temperature (WT), hydrogen ion concentration (pH), dissolved oxygen (DO), conductivity, turbidity (T), and chlorophyll-a (Chl-a) were measured in situ. Additionally, suspended solids (SS), ammonium nitrogen ($\mathrm{NH_4^+-N}$), nitrite nitrogen ($\mathrm{NO_2^--N}$), nitrate nitrogen ($\mathrm{NO_3^--N}$), total nitrogen (TN), total Kjeldahl nitrogen (TKN), total phosphate phosphorus, total organic carbon (TOC), chemical oxygen demand (COD), and fluoride ion (F^-) analyses were performed on the water samples collected at semimonthly periods during a one-year period from January to December 2014. The results of the study revealed that the Galyan and Kuştul streams feeding the dam lake are in the high quality water according to the TSWQR (2015). Bayhan et al. (2017) examined the water quality of the Ömerli Dam Lake, one of the largest dams supplying the drinking water demand of İstanbul Province. In the study, WT, pH, DO, T, Secchi disc depth, and Chl-a were measured in situ, and SS, NH_4^+, NO_2^-, NO_3^-, TKN, and phosphate analyses were conducted on the water samples collected from six stations and three different depths in the dam lake. As a result of the detailed classification of the Ömerli Dam Lake, it was determined to have slightly polluted water, but the lake was categorized as polluted water based on trophic level. Basturk (2019) investigated the water quality of Mamasın Dam Lake, which is used to supply the drinking water demand of Aksaray Province. Physico-chemical analyses were carried out for 35 indicators on water samples collected monthly between December 2015 and November 2016 from five stations and three different depths in the dam lake. As a result of the analyses, they determined that the Mamasın Dam Lake waters were suitable for industrial and agricultural use, but not suitable for drinking water supply without treatment. Kalipci et al. (2020) examined the water quality of the Yuvacık Dam Lake, which supplies 90% of the drinking water demand of Kocaeli Province. In the study, WT, pH, DO, conductivity, Chl-a, $NH_4^+ - N$, $NO_3^- - N$, TKN, TN, total phosphorus (TP), ortho-phosphate phosphorus, biochemical oxygen demand (BOD), COD, F^-, manganese ion (Mn^{2+}), and selenium water quality indicators were considered. Measurements and analyses of water quality indicators were carried out at five stations and five different depths in the dam lake between September 2016 and May. As a result of the analyses, it was found that the average values of water quality parameters of the dam lake change the range of high quality and slightly polluted water. Gedikoğlu (2021) investigated the water quality of the İkizcetepeler Dam Lake, which is used to meet the drinking water demand of Balıkesir Province, before and after treatment. In the study, daily pH, DO, T, conductivity, color, hardness, total organic matter, NH_4^+, NO_2^-, NO_3^-, aluminium ion (Al^{3+}), iron ion (Fe^{3+}), and Mn^{2+} data for the period of 2017-2019 were considered. It was determined that the dam lake water had high concentrations in terms of color, T, Fe^{3+}, and Mn^{2+} parameters. It was emphasized that the geological structure of the region and acid rains negatively affect the water quality and the dam lake basin should be protected. It was determined that the values of the related parameters of the İkizcetepeler Dam Lake waters after treatment were in accordance with the national standards. Coşkun (2022) investigated the water quality of water samples taken from 20 m depth of the Doğancı Dam Lake, which supply 80% of the drinking water demand of Bursa Province, before and after treatment. Measurements and analyses for 25 water quality indicators were performed weekly on the water samples between January 2018 and December 2018. It was determined that DO, sodium, and chloride ion (Cl^-) values increased and especially heavy metal levels decreased significantly after treatment. It was concluded that the geological structure of the basin, trophic level in the lake and organic pollution parameters are the parameters that affect the reservoir water quality the most and the Doğancı Dam Lake water is high quality.

Water quality indices (WQIs) are mathematical tools used to determine water quality and developed to assess whether a water resource is suitable for drinking purposes, agricultural irrigation, etc. These indices express water quality as a single numerical value by considering various physical, chemical, and biological parameters in water with a holistic approach (Banda et al., 2020). In addition, they provide the opportunity to compare changes over time in long-term monitoring studies. The WQIs have been widely used by researchers to assess the general ecological status and utilization potential of water resources (Sener et al., 2017; Kukrer and Mutlu, 2019; Mutlu et al., 2021; Muhammad et al., 2024).

The drinking water demand of Sinop Province, which is located in the northernmost part of Türkiye, is supplied from the Erfelek Dam Lake. In the literature, there are no studies on monitoring and assessment of water quality for the province. The aims of the study are to analyze and assess water quality of the Erfelek Dam Lake (i) before treatment considering WT, pH, DO, electrical conductivity (EC), T, total iron (Fe) and Mn^{2+} and (ii) after treatment considering $NH_4^+ - N$, $NO_2^- - N$, $NO_3^- - N$, chlorine (Cl_2), residual Cl_2, and copper ion (Cu^{2+}). The RCWIHC (2016) and TSWQR (2021) were considered for the assessments. Additionally, the water quality of the Erfelek Dam Lake was also evaluated with a holistic approach using Canadian Council of Ministers of the Environment water quality index (CCME-WQI).

2. Materials and Methods

2.1. The study area and water-quality data

With a coastline of 175 km, Sinop Province is located in the Turkish coast of Southern Black Sea, where the province with a surface area of 5862 km^2 is situated. Neighboring provinces are Kastamonu to the west, Çorum to the south, and Samsun to the southeast. Sinop has a typically moderate climate that is neither too warm in summers nor too cold in winters. Considering the meteorological records covering a long period between 1936 and 2018 from Sinop Meteorological Station, the mean minimum monthly temperature changes between 4.1°C in February and 20.3°C in August, while the mean maximum monthly temperature changes between 9.6°C in February and 26.3°C in August. Sinop receives a mean annual precipitation of 686.6 mm ranging from 32.6 mm in July to 90.5 mm in December. Mean annual precipitations in neighboring provinces are 481.9 mm in Kastamonu, 428.1 mm in Çorum, and 717.1 mm in Samsun, respectively.

The total population of the province is 229716, and 30.4% of which live in city centers according to the 2024 census (TÜİK, 2024). The sanitary sewage system serves 116327 people according to the Municipal Wastewater Statistics Survey in 2016. About 7.254×10^6 m^3 per year of wastewater are generated, 75.4% of which is discharged by deep sea discharge systems to the Black Sea, and 24.4% of which is discharged through the streams to the Black Sea (TÜİK, 2022).

The drinking water demand of Sinop city center, Gerze and Erfelek districts, and 48 villages in the province are supplied by the Erfelek Dam Lake on the Karasu Stream. The water taken from the lake is treated in the Sinop Municipality drinking water treatment plant, with a capacity of 54,000 m^3/day, and then transmitted to the tanks via water pipelines (Karadeniz, 2015; Baki et al., 2019). The location of the lake and the appearance of the treatment plant are illustrated in Figure 1. The quality of the water is analyzed using various parameters both before and after treatment.

Figure 1. (a) The Erfelek Dam Lake and (b) the drinking water treatment plant, Sinop Province, NE Türkiye (Baki et al., 2019)

In this study, WT, pH, DO, EC, T, Mn^{2+}, and total Fe parameters were considered in evaluating the water quality for the surface waters in the dam lake before treatment. Six more parameters, which are $NH_4^+ - N$, $NO_2^- - N$, $NO_3^- - N$, Cl_2, residual Cl_2, and Cu^{2+}, were considered in the assessing of the water quality for the water used for drinking purposes after treatment. The daily water quality data were obtained from Karadeniz (2015) for February 2014 to January 2015 and the website of Sinop Municipality (URL-1, 2024) for February 2023 to January 2024.

2.2. Canadian Council of Ministers of the Environment Water Quality Index

The CCME-WQI is developed to provide a clear and concise representation of water quality in rivers, lakes, and other freshwater resources. It calculates a single value to enable holistic assessment of various water quality parameters and performs the assessments using this value. The CCME-WQI is based on three factors, proportion of water quality parameters that do not meet the water quality guidelines (F_1), the percentage of individual test results that do not meet the standards (F_2), and the magnitude of deviation of failed tests exceeding the guideline (F_3). These factors are calculated using Eqs. (1)-(3).

$$\mathrm{F}_1 = \frac{\text{Number of failed parameters}}{\text{Total number of parameters}} \times 100 \tag{1}$$

$$\mathrm{F}_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \tag{2}$$

$$\mathrm{F}_3 = \frac{\sum \text{nse}}{\text{Number of failed tests}} \times 100 \tag{3}$$

In Eq. (3) nse is normalized sum of excursions and calculated by Eq. (4).

$$\text{nse} = \frac{\text{Failed test value}}{\text{Guideline value}} - 1 \tag{4}$$

The overall WQI score ranging from 0 to 100 is calculated by Eq. (5) using F_1, F_2, and F_3. Higher values indicate better water quality. CCME (2001) classified the WQI values in five groups as 100-95 (excellent, conditions are very close to natural or pristine levels), 94-80 (good, conditions are rarely depart from natural or desirable levels), 79-60 (conditions are sometimes depart from natural or desirable levels), 59-45 (conditions are often depart from natural or desirable levels), and 44-0 (conditions are usually depart from natural or desirable levels).

$$WQI = 100 - \sqrt{\left(\frac{F_1^2 + F_2^2 + F_3^2}{3}\right)} \tag{5}$$

The main factors for using the CCME-WQI in this study are that the index can be adapted to any water quality guideline depending on the intended use of the water and allows a wide range of parameters to be included in the calculations.

3. Findings and Discussion

In this study, the quality of both the Erfelek Dam Lake and treated waters were comprehensively assessed by considering the water quality indicators monitored before and after treatment. The water quality time series before and after treatment for the years 2014 and 2023 are given in Figures 2-14.

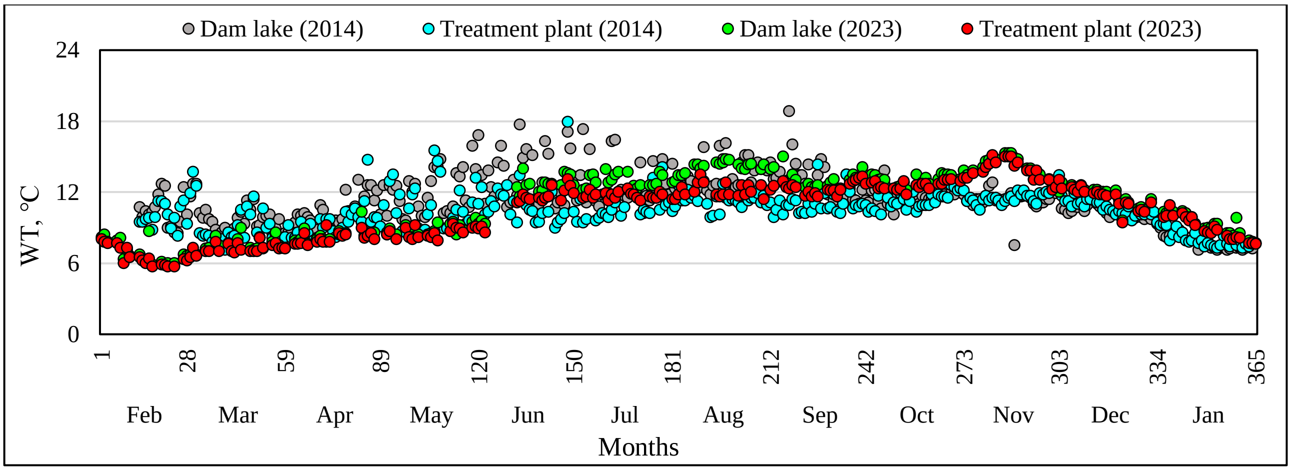

Figure 2. Water temperature time series, the drinking water treatment plant, Sinop Municipality (Karadeniz, 2015; URL-1, 2024)

The WT values ranged from 7.75 (January) to 13.53 °C (August) for before treatment and 7.97 (January) to 11.59 °C (November) after treatment in 2014. The values varied from 6.92 (February) to 14.10 °C (August) and 6.56 (February) to 13.82 °C (November) for before treatment and after treatment, respectively, in 2023. Before treatment, the lowest average WT was calculated as 9.09 °C (winter) in 2014, while it was 8.21 °C (spring) in 2023. The highest average WT were 13.23 °C (summer) and 13.35 °C (autumn) in 2014 and 2023, respectively. After a period of nine years, there was a decrease of 0.88 °C and an increase of 0.12 °C in the seasonal mean minimum and maximum WT values, respectively. The annual mean WT values before treatment were computed as 11.40 and 11.04 °C for the years 2014 and 2023, respectively. There is no available a specific range for the WT parameter in the amended TSWQR (2021). For both periods, however, the Erfelek Dam Lake was classified as high quality water according to TSWQR (2015) in terms of WT. Ersanli and Hasirci (2013) reported the WT for the Erfelek Dam Lake varied between 6.90 and 29.30 °C, with an average of 16.20 °C. On the other hand, Ersanli and Ozturk (2017) reported the WT ranged from 7.0 to 30.0 °C, with an average of 17.0 °C for the four different stations in the Karasu Stream, Sinop.

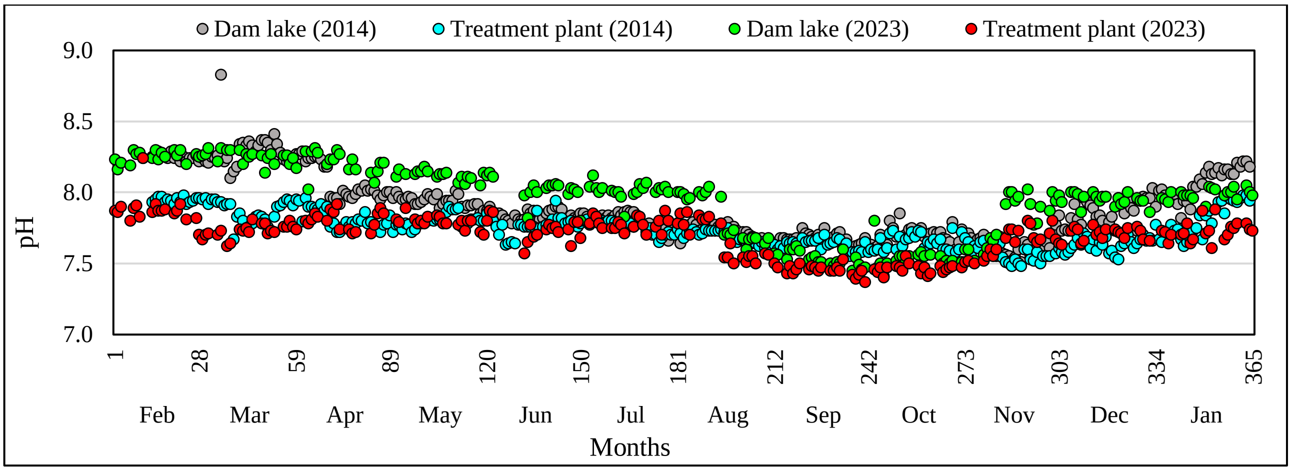

Figure 3. pH time series, the drinking water treatment plant, Sinop Municipality (Karadeniz, 2015; URL-1, 2024)

The pH values ranged from 7.63 (November) to 8.29 (March) before treatment and 7.56 (November) to 7.95 (February) after treatment, in 2014. The values varied from 7.53 (September) to 8.25 (February) and 7.45 (September) to 7.88 (February) before treatment and after treatment, respectively, in 2023. The pH values were lower in autumn compared to other seasons, with 7.67 (2014) and 7.63 (2023) before treatment and 7.62 (2014) and 7.52 (2023) for after treatment. The highest pH values were in spring: 8.10 (2014) and 8.19 (2023) before treatment and 7.62 (2014) and 7.77 (2023) after treatment. After a period of nine years, there was no significant change in pH values. For both periods, the Erfelek Dam Lake was classified as high quality water according to the TSWQR (2021), and pH values after treatment fell within the range imposed by the RCWIHC (2016). Ersanli and Hasirci (2013) reported pH values for the Erfelek Dam Lake varied between 7.8 and 8.6, with an average of 8.4. On the other hand, Ersanli and Ozturk (2017) reported pH values ranged from 6.0 to 8.0, with an average of 7.0 for the four monitoring stations in the Karasu Stream, Sinop. It means that the Erfelek Dam Lake and Karasu Stream are classified as high quality water based on the pH values.

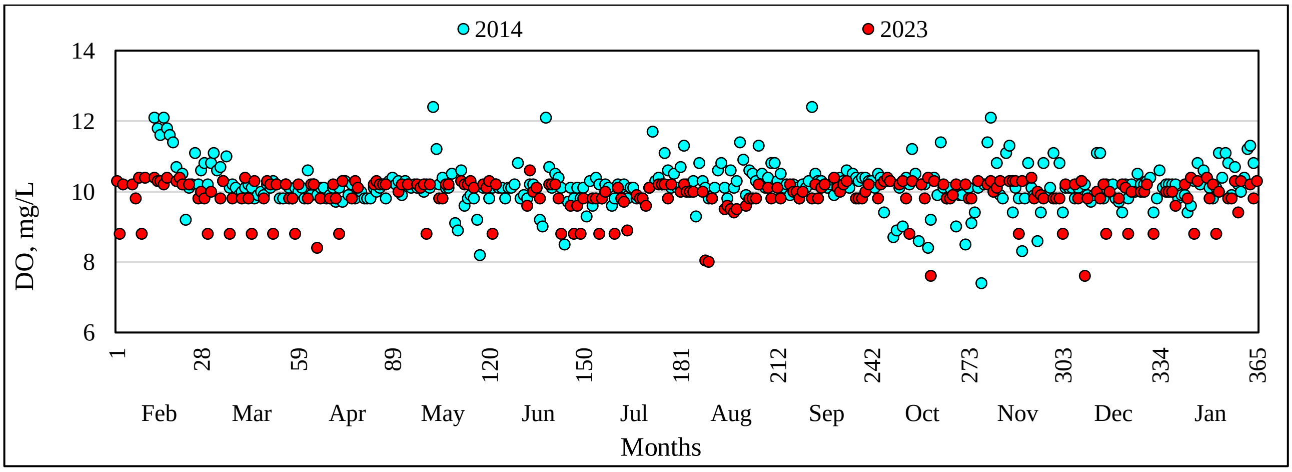

Figure 4. Dissolved oxygen time series, the drinking water treatment plant, Sinop Municipality (Karadeniz, 2015; URL-1, 2024)

The DO concentrations ranged from 9.86 (October) to 10.96 mg/L (February) in 2014 and 9.65 (August) to 13.92 mg/L (March) in 2023, respectively. The lowest seasonal concentrations were calculated as 10.07 and 9.71 mg/L for summer 2014 and spring 2023, respectively. On the other hand, the highest seasonal concentrations were 10.22 and 11.44 mg/L for autumn 2014 and summer 2023, respectively. Bayram (2017) reported that the winter presenting the coldest WT and the summer presenting the highest WT lead the higher and lower DO concentrations, respectively, in Değirmendere and Galyan streams, Trabzon. In this study, it is thought that the highest and lowest DO concentrations and WT occurred in different seasons because the treated water is taken from a certain depth in the Erfelek Dam Lake. The annual average DO concentrations were calculated as 10.18 mg/L for 2014 and 10.25 mg/L for 2023. Although there was no significant change in the concentrations on an annual basis, concentrations varied seasonally between 13.3% (spring) and –5.0% (summer) in the nine-year period. For both periods, the Erfelek Dam Lake was classified as high quality water according to the TSWQR (2021) in terms of DO concentration. Ersanli and Hasirci (2013) reported the DO concentrations for the Erfelek Dam Lake varied between 4.90 and 11.90 mg/L, with an average of 9.60 mg/L. On the other hand, Ersanli and Ozturk (2017) reported the DO concentrations ranged from 5.00 to 12.00 mg/L, with an average of 10.75 mg/L for the four monitoring stations in the Karasu Stream, Sinop.

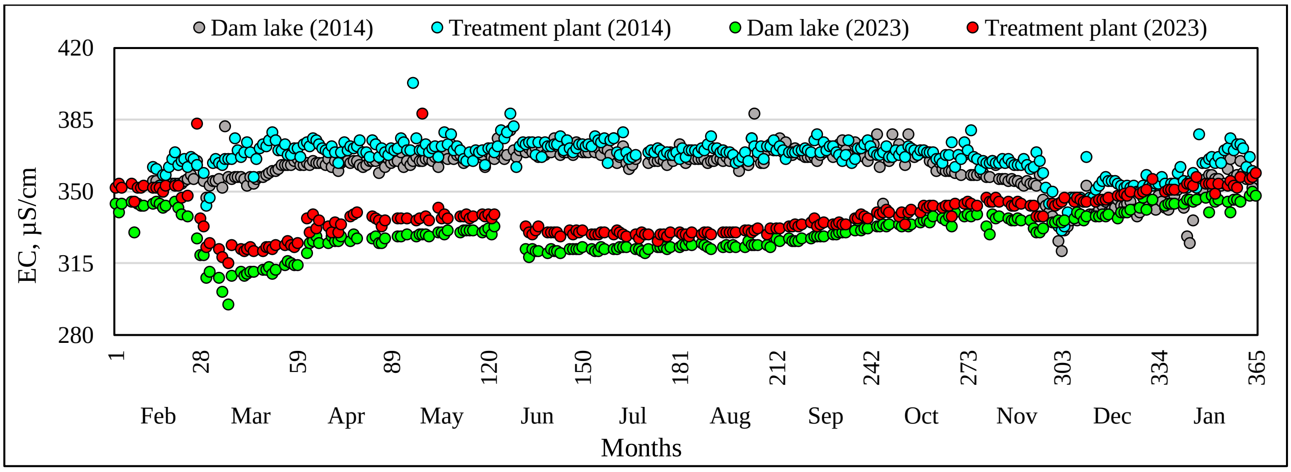

Figure 5. Electrical conductivity time series, the drinking water treatment plant, Sinop Municipality (Karadeniz, 2015; URL-1, 2024)

The EC values ranged from 341.19 (December) to 369.97 µS/cm (June) before treatment and 351.23 (December) to 373.27 µS/cm (June) after treatment in 2014. The values varied from 310.68 (March) to 345.27 µS/cm (January) and 320.54 (September) to 353.64 µS/cm (January) for before treatment and after treatment, respectively, in 2023. Before treatment, the highest seasonal values were 368.25 and 342.57 µS/cm in summer 2014 and winter 2023, respectively, and the lowest seasonal values were 346.03 and 321.68 µS/cm in winter 2014 and spring 2023, respectively. After treatment, the highest seasonal values were 371.28 and 350.81 µS/cm in summer 2014 and winter 2023, respectively, and the lowest seasonal values were 357.03 and 330.07 µS/cm in winter 2014 and summer 2023, respectively. After a period of nine years, the highest average EC values decreased 25.68 and 20.47 µS/cm before and after treatment, respectively. In addition, the lowest average values also decreased 24.35 and 26.96 µS/cm before and after treatment, respectively. For both periods, the Erfelek Dam Lake was classified as high quality water according to the TSWQR (2021) in terms of EC parameter. Furthermore, the EC values after treatment were lower than the limit value in the RCWIHC (2016). Ersanli and Hasirci (2013) reported the EC values for the Erfelek Dam Lake varied between 235.70 and 378.00 µS/cm, with an average of 341.40 µS/cm. On the other hand, Ersanli and Ozturk (2017) reported the EC values ranged from 296.00 to 894.00 µS/cm, with an average of 450.50 µS/cm for the four monitoring stations in the Karasu Stream, Sinop.

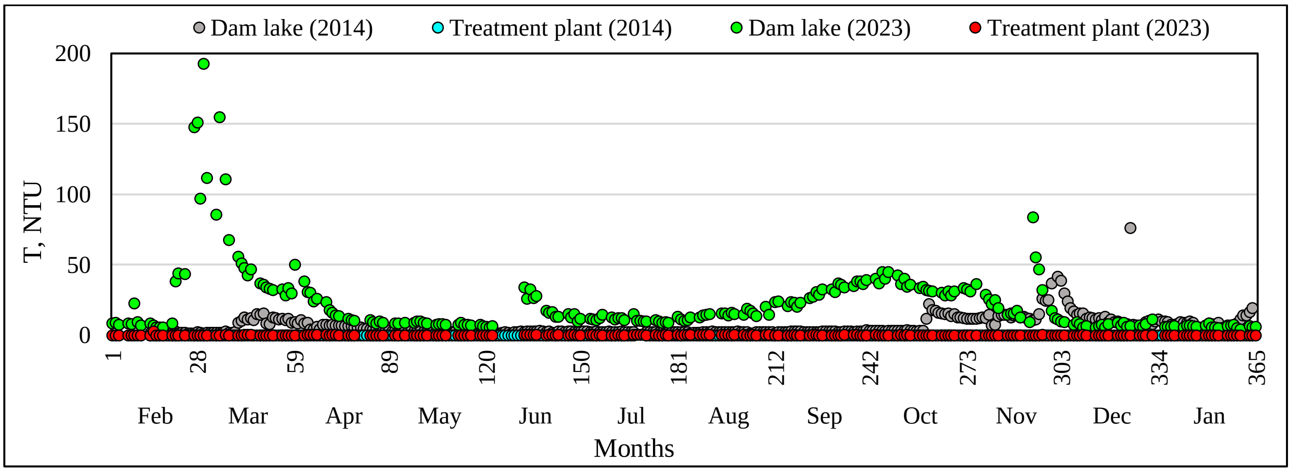

Figure 6. Turbidity time series, the drinking water treatment plant, Sinop Municipality (Karadeniz, 2015; URL-1, 2024)

The T values ranged from 1.89 (February) to 16.64 NTU (November) before treatment and 0.04 (June) to 0.13 NTU (March) after treatment in 2014. The values varied from 6.32 (January) to 64.23 NTU (March) and 0.12 (November) to 0.36 NTU (February) before and after treatment, respectively, in 2023. Before treatment, the highest seasonal T values were 11.65 and 31.54 NTU in winter 2014 and spring 2023, respectively, and the lowest seasonal values were 2.39 and 6.91 NTU in summer 2014 and winter 2023, respectively. After treatment, the highest seasonal values were 0.08 and 0.3 NTU in spring 2014 and summer 2023, respectively, and the lowest seasonal values were 0.06 and 0.15 NTU in summer 2014 and winter 2023, respectively. The annual average T values in 2014 and 2023 were calculated as 6.67 and 22.75 NTU before treatment, respectively, and 0.07 and 0.21 NTU after treatment, respectively. There is a significant difference (246.3% before treatment and 191.7% after treatment) in average T values on annual basis in the nine-year period. There is no classification for the T in the TSWQR (2015) and TSWQR (2021). However, it is stated that T values should be less than 1 NTU in treated drinking water in the RCWIHC (2016). All values satisfy this condition.

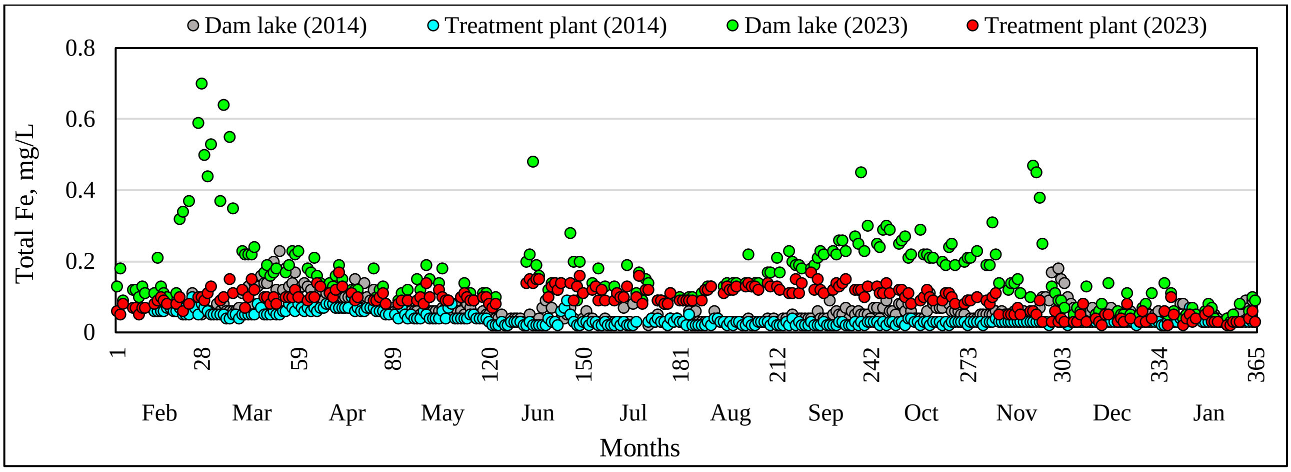

Figure 7. Total iron ion time series, the drinking water treatment plant, Sinop Municipality (Karadeniz, 2015; URL-1, 2024)

The total Fe concentrations ranged from 0.03 (February) to 0.11 mg/L (November) before treatment and 0.02 (September) to 0.07 mg/L (April) after treatment in 2014. The values varied from 0.06 (January) to 0.29 mg/L (March) and 0.04 (January) to 0.13 mg/L (September) before and after treatment, respectively, in 2023. Before treatment, the highest seasonal concentrations were 0.09 and 0.22 mg/L in spring 2014 and autumn 2023, respectively, and the lowest seasonal concentrations were 0.04 and 0.07 mg/L in summer 2014 and winter 2023, respectively. After treatment, the highest seasonal concentrations were 0.06 and 0.12 mg/L in spring 2014 and summer 2023, respectively, and the lowest seasonal concentrations were 0.03 and 0.04 mg/L in winter for both periods. The annual average total Fe concentrations belonging in 2014 and 2023 were calculated as 0.06 and 0.17 mg/L before treatment, respectively, and 0.04 and 0.09 mg/L after treatment, respectively. There is a significant difference (increase 167.9% before treatment and 146.5% after treatment) in average concentrations on annual basis in the nine-years period. There is no available a specific range for the total Fe parameter in the amended TSWQR (2021). According to the TSWQR (2015), however, the Erfelek Dam Lake was classified as high quality water for both periods in terms of total Fe concentration. However, total Fe concentrations after treatment fell within range imposed by the RCWIHC (2016).

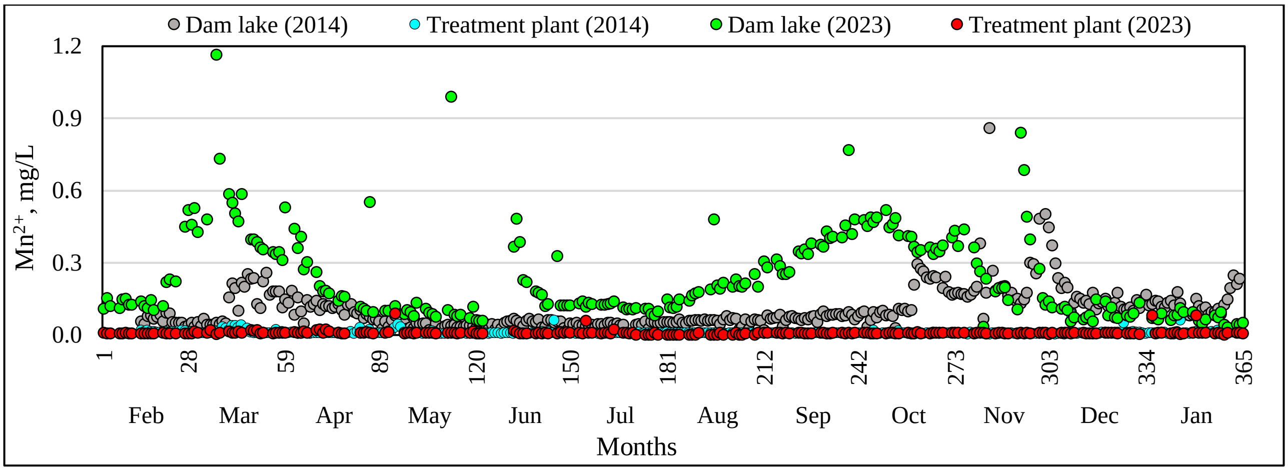

Figure 8. Manganese ion time series, the drinking water treatment plant, Sinop Municipality (Karadeniz, 2015; URL-1, 2024)

The Mn^{2+} concentrations ranged from 0.04 (May) to 4.80 mg/L (April) before treatment and 0.006 (November) to 0.016 mg/L (March) after treatment in 2014. The values varied from 0.070 (January) to 0.541 mg/L (March) before treatment and 0.004 (August) to 0.014 mg/L (January) after treatment in 2023. Before treatment, the highest seasonal Mn^{2+} concentrations were 0.157 and 0.363 mg/L in autumn 2014 and 2023, respectively, and the lowest seasonal concentrations were 0.050 and 0.081 mg/L in summer 2014 and winter 2023, respectively. After treatment, the highest seasonal concentrations were 0.012 mg/L in spring 2014 and summer 2023, and the lowest seasonal concentrations were 0.007 mg/L in autumn 2014 and summer 2023. The annual average Mn^{2+} concentrations belonging in 2014 and 2023 were calculated as 0.106 and 0.242 mg/L before treatment, respectively, and 0.010 and 0.009 mg/L after treatment, respectively. After a period of nine years, there is a significant difference (an increase of 128.3%) in average concentrations on annual basis before treatment. According to the TSWQR (2021), the Erfelek Dam Lake was classified as slightly polluted water for both periods in terms of Mn^{2+} parameter. Additionally, Mn^{2+} concentrations after treatment fell within the range imposed by the RCWIHC (2016).

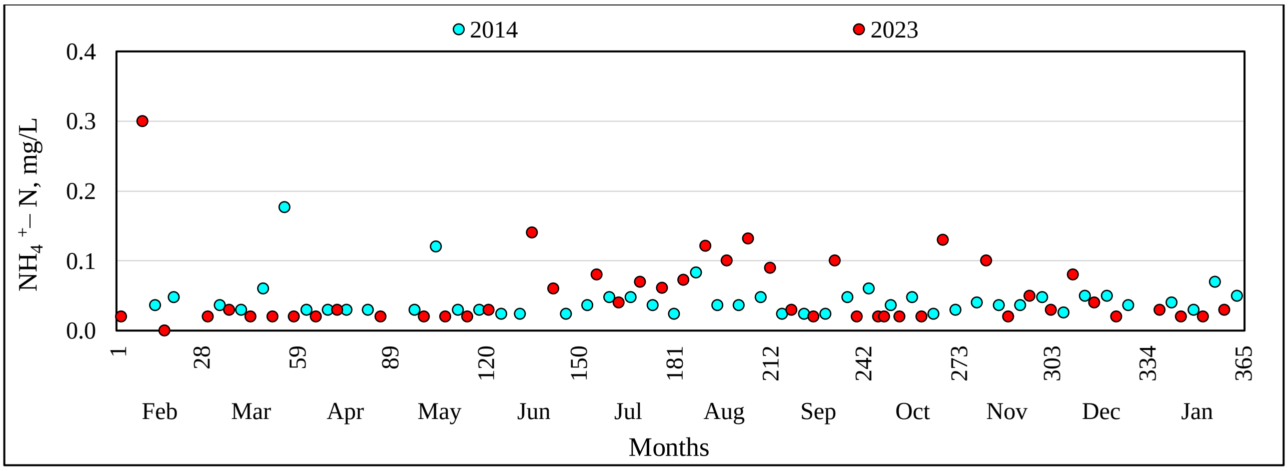

Figure 9. Ammonium nitrogen time series after treatment (Karadeniz, 2015; URL-1, 2024)

The $NH_4^+ - N$ concentrations ranged from 0.02 (June) to 0.08 mg/L (March) in 2014 and 0.02 (May) to 0.11 mg/L (February) in 2023. The lowest and highest seasonal average concentrations were calculated as 0.037 (autumn) and 0.053 mg/L (spring), respectively, in 2014. After a period of nine years, the values were 0.022 (spring) and 0.083 mg/L (summer) in 2023. Seasonal minimum concentrations decreased by 40.2% and maximum concentrations increased by 57.4%. On an annual basis, it increased by 20. 6%. In addition, the seasons, in which extreme values, are observed differ for both periods. $NH_4^+ - N$ concentrations, however, fell within range imposed by the RCWIHC (2016).

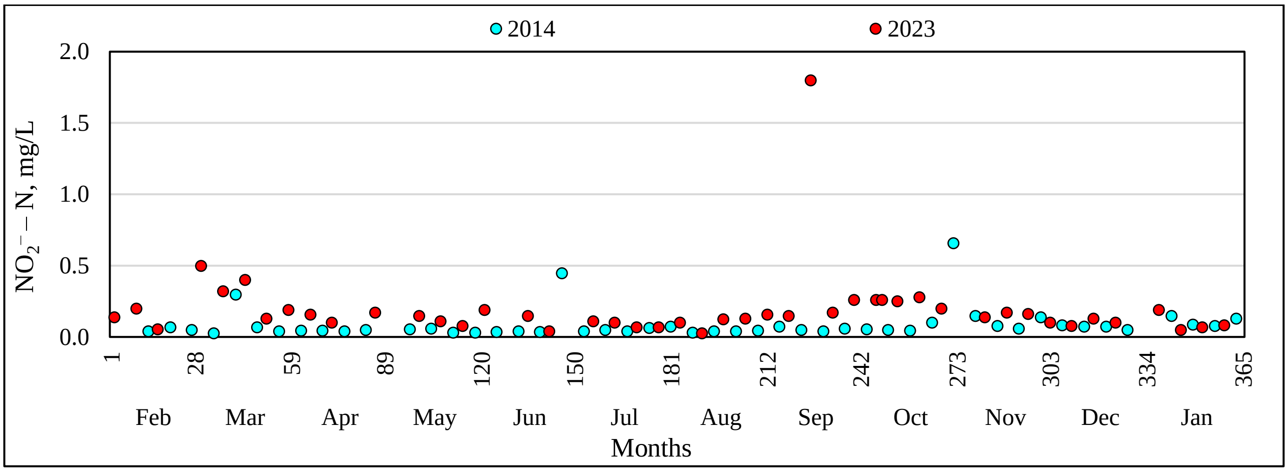

Figure 10. Nitrite nitrogen time series after treatment (Karadeniz, 2015; URL-1, 2024)

The $NO_2^- - N$ concentrations ranged from 0.02 (August) to 0.08 mg/L (October) in 2014 and 0.09 (July) to 0.60 mg/L (September) in 2023. The lowest and highest seasonal average concentrations were calculated as 0.066 (spring) and 0.121 mg/L (autumn), respectively, in 2014. After a period of nine years, the values were 0.101 (winter) and 0.323 mg/L (autumn) in 2023. Seasonal minimum and maximum concentrations increased by 51.6 and 167.3%, respectively. On an annual basis, it increased by 122.7%. $NO_2^- - N$ concentrations, however, were lower than the limit value imposed by the RCWIHC (2016).

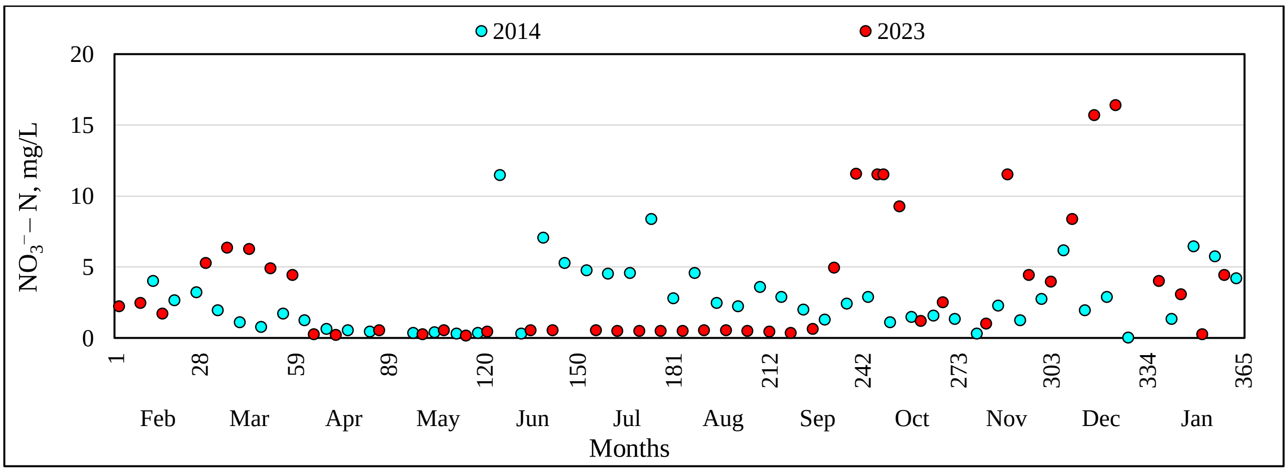

Figure 11. Nitrate nitrogen time series after treatment (Karadeniz, 2015; URL-1, 2024)

The $NO_3^- - N$ concentrations ranged from 0.36 (May) to 6.04 mg/L (June) in 2014 and 0.33 (May) to 13,50 mg/L (December) in 2023. The lowest and highest seasonal average concentrations were calculated as 0.83 (spring) and 4.79 mg/L (summer), respectively, in 2014. After a period of nine years, the values were 0.52 (summer) and 7.47 mg/L (winter) in 2023. Seasonal minimum concentrations decreased by 37.4% and maximum concentrations increased by 56.1%. On an annual basis, it increased by 33.5%. Additionally, the seasons in which extreme values are observed vary between the two periods. $NO_3^- - N$ concentrations, however, were lower than the limit value imposed by the RCWIHC (2016).

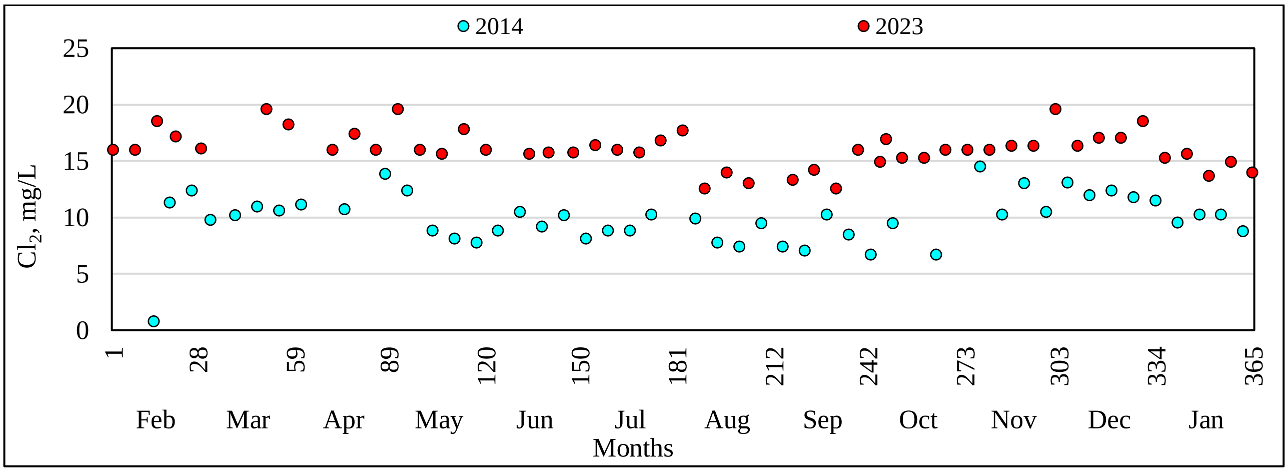

Figure 12. Chlorine time series after treatment (Karadeniz, 2015; URL-1, 2024)

The Cl_2 concentrations ranged from 7.66 (October) to 12.18 mg/L (December) in 2014 and 14.05 (September) to 18.02 mg/L (March) in 2023. The lowest and highest seasonal average concentrations were calculated as 9.14 (summer) and 11.10 mg/L (winter), respectively, in 2014. After a period of nine years, the values were 15.43 (summer) and 17.15 mg/L (spring) in 2023. Seasonal minimum and maximum concentrations increased by 68.7 and 54.6%, respectively. On an annual basis, it decreased by 63.1%. The Cl_2 concentrations were lower than the limit value of 250 mg/L imposed by the RCWIHC (2016).

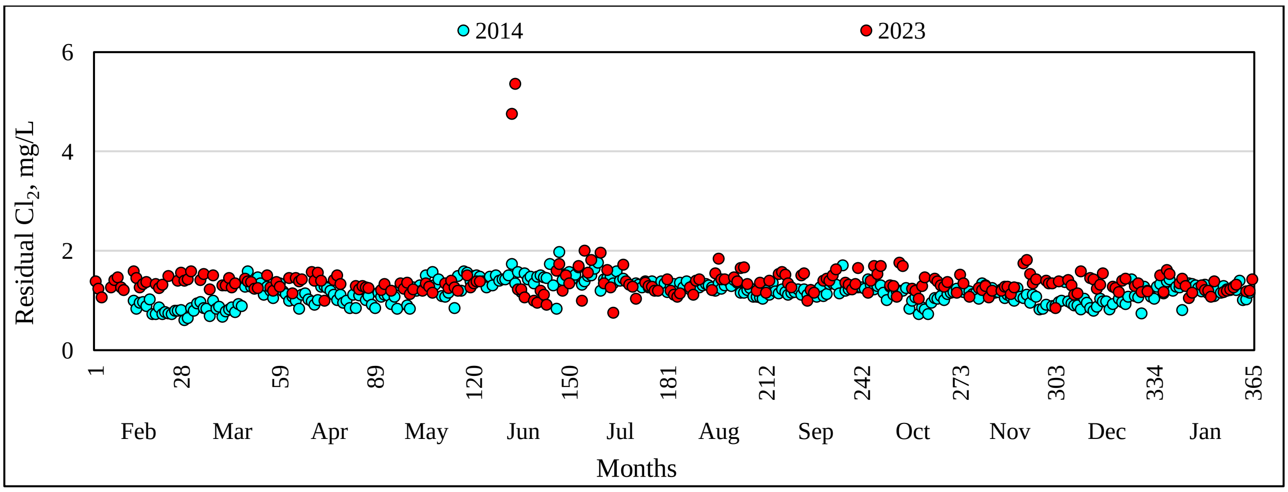

Figure 13. Residual chlorine time series after treatment (Karadeniz, 2015; URL-1, 2024)

The residual Cl_2 concentrations ranged from 0.83 (February) to 1.45 mg/L (June) in 2014 and 1.28 (January) to 1.70 mg/L (July) in 2023. The lowest and highest seasonal average concentrations were calculated as 1.09 (spring) and 1.37 mg/L (summer), respectively. After a period of nine years, the values were 1.30 (winter) and 1.47 mg/L (summer) in 2023. Seasonal minimum and maximum concentrations increased by 19.1 and 7.4%, respectively. On an annual basis, it decreased by 17.6%. The residual Cl_2 concentrations were higher than the range of 0.2 - 0.5 mg/L imposed by the RCWIHC (2016).

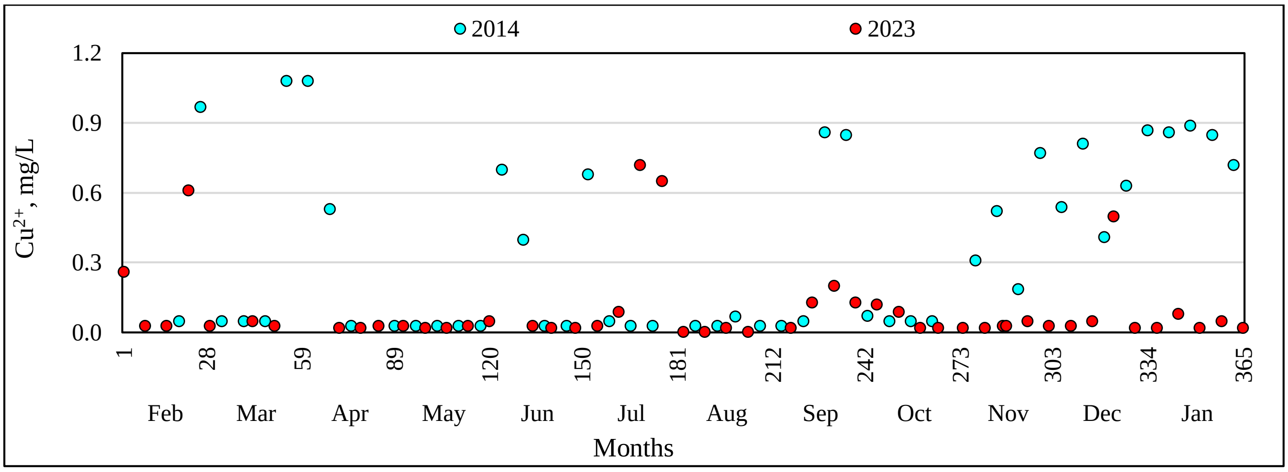

Figure 14. Copper ion time series after treatment (Karadeniz, 2015; URL-1, 2024)

The Cu^{2+} concentrations ranged from 0.03 (May) to 0.83 mg/L (January) in 2014 and 0.01 (August) to 0.37 mg/L (July) in 2023. The lowest and highest seasonal average concentrations were calculated as 0.180 (summer) and 0.731 mg/L (winter), respectively, in 2014. After a period of nine years, the values were 0.03 (spring) and 0.14 mg/L (summer) in 2023. seasonal minimum and maximum concentrations decreased by 82.9 and 80.3%, respectively. On an annual basis, it decreased by 73.6%. Cu^{2+} concentrations were lower than the limit value imposed by the RCWIHC (2016).

Basic statistics of water quality indicators monitored in the Sinop Municipality drinking water treatment plant before treatment, along with the limit values referenced to the TSWQR (2015) and TSWQR (2021), are presented in Table 1. The statistics for these indicators after treatment, along with the mandatory values imposed by the RCWIHC (2016), are provided in Table 2.

Table 1. Basic statistics of water quality indicators before treatment and limit values for the TSWQR (2015) and TSWQR (2021)

Indicator	Unit	Year	Min	Ave	Max	SD	TSWQR (2015)				TSWQR (2021)		
							High quality	Slightly polluted	Polluted	Too much polluted	High quality	Slightly polluted	Polluted
WT	°C	2014	7.10	11.40	18.80	2.15	≤25	≤25	≤30	≥30	-	-	-
		2023	5.90	11.04	15.30	2.64							
pH		2014	7.51	7.89	8.83	0.22	6.5-8.5	6.5-8.5	6.0-9.0	<6.0 >9.0	6.0-9.0	6.0-9.0	6.0-9.0
		2023	7.41	7.95	8.31	0.25							
DO	mg/L	2014	7.40	10.18	12.40	0.62	>8.0	6.0	6.0	<3.0	>8.00	6.00	<6.00
		2023	7.60	9.88	10.60	0.52							
EC	µS/cm	2014	321.00	360.87	388.00	10.38	<400	1000	3000	>3000	<400	1000	>1000
		2023	295.00	330.02	350.00	9.95							
T	NTU	2014	1.26	6.57	76.30	7.08	-	-	-	-	-	-	-
		2023	4.52	22.75	193.00	24.89							
Total Fe	mg/L	2014	0.02	0.06	0.23	0.03	<0.3	1.0	5.0	≥5.0	-	-	-
		2023	0.03	0.17	0.70	0.11							
Mn^{2+}	mg/L	2014	0.02	0.11	0.86	0.09	<0.1	0.5	3.0	≥3.0	0.10	0.50	>0.50
		2023	0.03	0.24	1.66	0.20							

Table 2. Basic statistics of water quality indicators after treatment and mandatory values imposed by the RCWIHC (2016)

Indicator	Unit	Year	Min	Ave	Max	SD	RCWIHC (2016)
WT	°C	2014	7.10	10.45	17.90	1.58	-
		2023	5.70	10.46	15.10	2.38	
pH		2014	7.48	7.74	7.98	0.12	6.50 - 9.50
		2023	7.37	7.69	8.24	0.14	
DO	mg/L	2014	-	-	-	-	-
		2023	-	-	-	-	
EC	µS/cm	2014	331.00	366.88	403.00	8.33	2500
		2023	315.00	338.50	388.00	10.35	
T	NTU	2014	0.01	0.07	0.25	0.05	-
		2023	0.01	0.21	3.00	0.21	
Total Fe	mg/L	2014	0.02	0.04	0.10	0.02	0.20
		2023	0.02	0.09	0.17	0.04	
Mn^{2+}	mg/L	2014	0.001	0.010	0.090	0.008	0.05
		2023	0.001	0.009	0.090	0.010	
$NH_4^+ - N$	mg/L	2014	0.02	0.04	0.18	0.03	0.50
		2023	0.00	0.05	0.30	0.05	
$NO_2^- - N$	mg/L	2014	0.03	0.09	0.66	0.11	0.50
		2023	0.03	0.19	1.80	0.26	
$NO_3^- - N$	mg/L	2014	0.05	2.75	11.47	2.37	50
		2023	0.16	3.67	16.40	4.39	
Cl_2	mg/L	2014	0.83	9.86	14.55	2.31	250
		2023	12.60	16.08	19.62	1.65	
Residual Cl_2	mg/L	2014	0.61	1.17	1.98	0.23	-
		2023	0.75	1.37	5.36	0.38	
Cu^{2+}	mg/L	2014	0.03	0.35	1.08	0.37	2.00
		2023	0.002	0.093	0.720	0.168	

SD: Standard deviation

The water quality of the Erfelek Dam Lake was evaluated by CCME-WQI. Seven parameters including pH, WT, DO, EC, T, total Fe, and Mn^{2+} were considered in the index calculation. The limit values specified in the TSWQR (2021) were used for the relevant parameters in the calculations. There is no a limit value specified for T values in the TSWQR (2021). For this reason, a value of 5 NTU specified in WHO (2002) was accepted as the limit for T values. For the Erfelek Dam Lake, the monthly WQI values varied between 70.4 and 100.0 in 2014 and between 72.7 and 83.5 in 2023 (Figure 15).

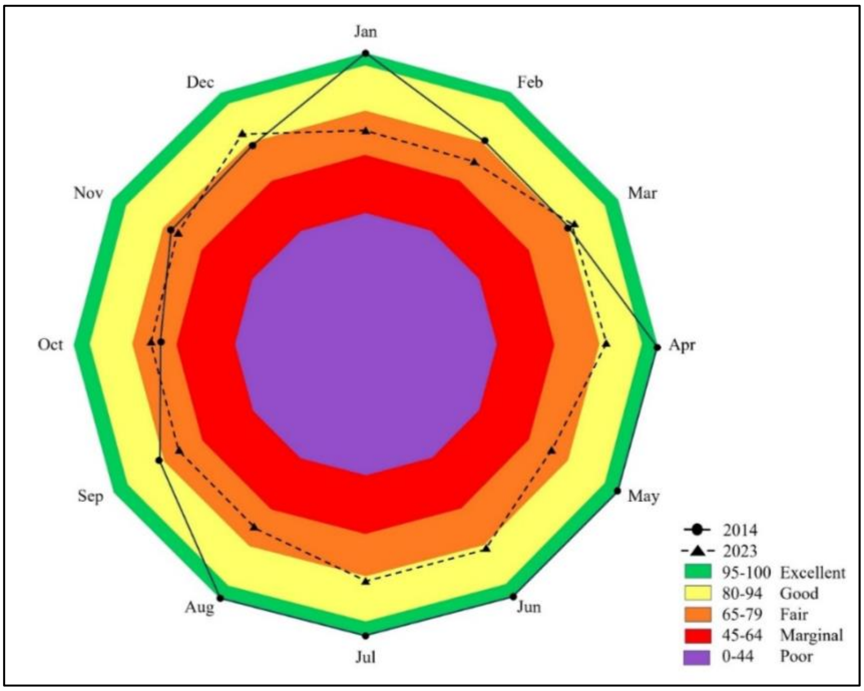

Figure 15. Application of the CCME water quality index for the Erfelek Dam Lake, Karasu Stream, Sinop, Türkiye

The WQI values for 2023 are slightly higher than 2014 in March, October and December. In the rest of months, it is observed that the WQI values of 2014 are higher. Especially in January, April, May, June, July, and August, the WQI values of 2023 are significantly lower compared to 2014. This is caused by T values and Mn^{2+} concentrations exceeded the specified limit values many times in the relevant months of 2023. In the study conducted by Kukrer and Mutlu (2019) to evaluate the water quality of the Saraydüzü Dam Lake (Sinop, Türkiye), it was reported that WQI values were lower in winter months and higher in summer months. A similar situation was observed in the WQI values calculated for 2014 (except February) and 2023 (except January) in the Erfelek Dam Lake. In this study, unlike Boskidis et al. (2010) and Singh et al. (2017), no decrease in water quality was observed in summer months. It is thought that this may be due to the different parameters evaluated. According to the annual average WQI values, the Erfelek Dam Lake was classified as good (89.1) in 2014 and fair (77.3) in 2023 in terms of drinking water quality.

4. Conclusions and Recommendations

In this study, the water quality of the Erfelek Dam Lake was meticulously assessed before and after treatment process. Before treatment parameters such as water temperature, hydrogen ion concentration (pH), dissolved oxygen, electrical conductivity (EC), turbidity (T), total iron, and manganese ion (Mn^{2+}) were analyzed to determine the condition of the surface water. After treatment analysis focused on six more parameters including ammonium nitrogen, nitrite nitrogen, nitrate nitrogen, chlorine, residual chlorine, and copper ion (Cu^{2+}) to assess the effectiveness of the water treatment process. The assessments were conducted in accordance with the Turkish Surface Water Quality Regulation (TSWQR, 2021) and Regulation Concerning Water Intended for Human Consumption (RCWIHC, 2016) to ensure comprehensive and accurate results. Finally, the Canadian Council of Ministers of the Environment water quality index values were calculated to assess the water quality of the Erfelek Dam Lake. For the monitoring periods 2014 and 2023, changes in water quality were compared by using the calculated WQI values. The main findings of the study are given below.

As a result of one-year monitoring for both periods, it was concluded that the Erfelek Dam Lake has high quality water according to the TSWQR (2021) in terms of monitored water quality indicators, except for Mn^{2+} concentrations. The lake is classified as slightly polluted water in terms of Mn^{2+} concentrations.

In the Erfelek Dam Lake, the maximum and minimum average values of water quality indicators except pH occurred in different seasons for the years 2014 and 2023. In addition, when the annual averages of these parameters (except for EC) were examined, higher values were calculated in 2023 compared to 2014.

It was determined that the values belonging to the water quality indicators considered after treatment were lower than the limit values imposed by the RCWIHC (2016).

Calculated WQI values indicate a significant deterioration in the water quality of the Erfelek Dam Lake in 2023 compared to 2014. The decrease in the WQI values, particularly in the summer months, can be attributed to frequent exceedances in T values and Mn^{2+} concentrations. This highlights the need for enhanced monitoring and management efforts to address the factors impacting water quality, particularly during the warmer months.

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Authors' Contributions

All authors contributed equally to the study.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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