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Araştırma (Research)

Assessment of Bendimahi Stream (Van, Türkiye) Water Quality Criteria in Terms of Human Consumption

Özgür Bulut BULUM[1], **Fazıl ŞEN**[1*]

[1]Yüzüncü Yıl University, Faculty of Irrigation, and Fisheries, Van/TÜRKİYE

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Sorumlu yazar: Fazıl ŞEN, e-posta: fazilsen@yyu.edu.tr

Abstract

Objective: This study aims to determine the water quality criteria of the Bendimahi Stream and to evaluate its usability for human consumption, irrigation, and fisheries.

Materials and Methods: In this study, water temperature, pH, electrical conductivity, dissolved oxygen, oxygen saturation, salinity, and turbidity of the Bendimahi Stream were determined by in-situ measurements and observations, while parameters such as Ca, Mg, total hardness, Cl, CO_3, HCO_3, total alkalinity, NO_2, NO_3, NH_3, SO_4, P, K, Al, Fe, Mn, Cu, Zn, Cr, F, and CN were analyzed in the laboratory in monthly periods for one year.

Results: In this study, the water quality parameters of the Bendimahi Stream, as specified in the materials and methods section were analyzed, the findings were given in tables , and and the usability of the stream for drinking water, irrigation and fishing purposes was evaluated.

Conclusion: In terms of drinking water quality, the stream falls into Class I for parameters such as temperature, dissolved oxygen, dissolved oxygen saturation, chloride, nitrate, nitrite, sulfate, potassium, copper, aluminum, total iron, zinc, and cyanide; Class II for ammonium-ammonia, pH, chromium, fluoride, and phosphorus; and Class III for manganese.

Keywords: water quality, irrigation, fisheries, drinking, Van, Türkiye

Bendimahi Çayı Su Kalite Kriterlerinin İnsani Tüketim, Sulama ve Balıkçılık Açısından Değerlendirilmesi

Öz

Amaç: Bu çalışmada Bendimahi Çayı'nın su kalitesi kriterlerinin belirlenmesi ve su kaynaklarının insani tüketim, sulama ve balıkçılık açısından kullanılabilirliğinin değerlendirilmesi amaçlanmıştır.

Materyal ve Yöntem: Çalışmada, Bendimahi Çayı’nın su sıcaklığı, pH, elektriksel iletkenlik, çözünmüş oksijen, oksijen doygunluğu, tuzluluk ve bulanıklık değerleri yerinde ölçümler ve gözlemlerle belirlenmiş; Ca, Mg, toplam sertlik, Cl, CO_3, HCO_3, toplam alkalinite, NO_2, NO_3, NH_3, SO_4, P, K, Al, Fe, Mn, Cu, Zn, Cr, F ve CN gibi parametreler ise bir yıl boyunca aylık periyotlarla laboratuvarda analiz edilmiştir.

Araştırma Bulguları: Çalışmada, Bendimahi Çayı'nın materyal ve yöntem bölümünde belirtilen su kalite parametreleri analiz edilerek; bulgular çizelgeler halinde verilmiş, çayın içme suyu, sulama ve balıkçılık amacıyla kullanılabilirliği değerlendirilmiştir.

Sonuç: İçme suyu kalitesi açısından; sıcaklık, çözünmüş oksijen, çözünmüş oksijen doygunluğu, klorür, nitrat, nitrit, sülfat, potasyum, bakır, alüminyum, toplam demir, çinko ve siyanür gibi parametrelerde I. sınıf; amonyum-ammoyak, pH, krom, florür ve fosfor parametrelerinde II. sınıf; mangan açısından ise III. sınıf su kalitesine sahiptir.

Anahtar Kelimeler: su kalitesi, sulama, balıkçılık, insani tüketim, Van, Türkiye

Introduction

All living beings depend on water to sustain their lives. Water, used in many areas such as drinking water, irrigation, fish farming, various industrial activities, and meeting human recreational needs, covers three-quarters of the Earth's surface in the form of seas and oceans, rivers and lakes, snow, and glaciers (Cirik and Cirik, 2005).

However, despite its abundance, the amount of usable water constitutes less than 1% of the total available water (Şen, 2016). Therefore, minimizing the discharge of pollutants into water bodies and avoiding the use of aquatic environments-particularly rivers and streams-for waste disposal is of critical importance.

Continuous monitoring of water resources is essential, and any anomalous values should be promptly investigated and addressed through appropriate corrective measures.

Extensive research has been conducted on the monitoring and assessment of water resources in the Van Lake Basin, including the Bendimahi Stream-the primary subject of this study-and adjacent regions. (Şen and Aksoy 2015; Atıcı et al. 2016; Çavuş et al. 2017; Atıcı et al. 2018; Şen and Şekerci 2019; Atıcı et al. 2020; Çavuş and Şen 2020a; Çavuş and Şen 2020b; Atıcı et al. 2021a; Atıcı et al. 2021b; Demir and Şen 2021; Atıcı et al. 2022; Aydın and Şen 2022; Çavuş and Şen 2022; Kaya and Şen 2022; Atıcı et al. 2023; Çavuş and Şen 2023; Kaya et al. 2023).

This study aims to determine the water quality criteria of the Bendimahi Stream and to evaluate its usability for human consumption, irrigation, and fisheries.

Materials and Methods

Study Area

The Bendimahi Stream, which constitutes the study area, is one of the major water catchment basins of the Lake Van Basin and is located in the northeastern part of Lake Van, within the borders of Çaldıran and Muradiye districts. The stream has a basin of approximately 1,761 km^2, an altitude range between 1,641 and 3,645 m, and a length of about 90 km. It flows into Lake Van from the boundaries of Karahan village along the lake's shore. The stream features the Muradiye Waterfall, two hydroelectric power plants (HEPPs), and one irrigation regulator. In some years, parts of the stream freeze during the winter months. It is home to fish species such as *Cyprinus carpio* (common carp), the endemic *Capoeta kosswigi* (Van barb, endemic), *Alburnus tarichi* (tarek, endemic), and *Oxynoemacheilus ercisianus* (Erciş loach, endemic) (Elp et al. 2014; Şen et al. 2015; Elp et al. 2016; Şen et al. 2018).

The study was conducted based on monthly samples collected over the course of one year (from December to November) at six sampling points along the stream (Figure 1).

Figure 1. The sampling points of Bendimahi Stream

Field and Laboratory Analyses of Water Quality Parameters

In situ measurements of water temperature (Temp), pH, electrical conductivity (Con), dissolved oxygen (DO), dissolved oxygen saturation (OS), and salinity were conducted using a multiparameter device (Hach-HQ40D), while turbidity (Tur) was measured using a turbidimeter (Hach-2100Q). Following the completion of field measurements, water samples were collected in 1.5-liter bottles and transported to the laboratory for further analysis. Both titrimetric and spectrophotometric methods were employed in the laboratory phase.

Calcium, magnesium, and total hardness (T.Hard.) were determined via ethylenediaminetetraacetic acid (EDTA) titration, while total chloride content was analyzed using argentometric titration (Mohr-Knudsen method). Carbonate, bicarbonate, and total alkalinity (T.Alk.) levels were assessed through hydrochloric acid (HCl) titration (APHA, 1989; Çetinkaya, 2003). Furthermore, the concentrations of ammonium and ammonia (method 8038), nitrate (8039), nitrite (8507), phosphate (8048), sulfate (8051), potassium (8049), copper (8143), aluminum (8012), iron (8112), zinc (8009), chromium (8023), manganese (8034), cyanide (8027), and fluoride (8029) were quantified using Hach standard methods with a Hach-Lange DR 5000 UV-VIS spectrophotometer (Hach, 2005).

The interpretation of results was carried out with reference to national and international water quality standards and regulatory frameworks, particularly within the contexts of potable water supply, fisheries, and irrigation. These included Atabey (2015), Ayers and Wescot (1994), Tebbut (1998), the Water Intended for Human Consumption Regulation (WHCR 2005), TS 266/T3 Standard for Water Intended for Human Consumption (TSE, 2022), the Surface Water Quality Management Regulation (SWQR, 2012), and the Quality and Treatment of Water Supplied for Drinking Purposes Regulation (QTWDR, 2019). Additionally, guidelines from the World Health Organization (WHO 2022), and relevant European Union directives on drinking water (EUDWR) (SI No. 99 of 2023) and water for fish life (78/659/EEC) were taken into account (Tebbut 1998, EUDWR 2023).

Results and Discussion

Hydrological and Ecological Significance of the Bendimahi Stream

The Bendimahi Stream, originating from the Aladağlar and Tendürek Mountains and discharging the waters collected in the Kaz Lake basin, represents the highest-discharge stream within the Lake Van Basin. It plays a vital ecological role as a spawning and habitat area for several fish species, including *Cyprinus carpio* (common carp), *Alburnus tarichi* (tarek, endemic), *Capoeta kosswigi* (Van barb, endemic) and *Oxynoemacheilus ercisianus* (Erciş loach, endemic(Elp et al. 2014, Şen et al. 2015, Elp et al. 2016, Şen et al. 2018). In addition to its ecological significance, the stream also supports the region's agriculture through irrigation, provides drinking water for both humans and livestock, and contributes to energy production via two HEPPs and one irrigation regulator. Recreational and ecological interest peaks particularly during the spawning migration of the pearl mullet, notably at the Muradiye Waterfalls and the fish migration monitoring site located at the Muradiye district entrance.

During the study, in-situ measurements and titrimetric analyses conducted on samples brought to the laboratory from six different sampling points were presented as average values in Table 1 and Table 2, while the average values of spectrophotometric analyses (non metals and metals) were presented in Table 3 and Table 4.

Water Temperature

Water temperature is a primary determinant of aquatic ecosystem health, influencing both water quality parameters (such as taste, gas and solid solubility, conductivity, dissolved oxygen, and pH) and physiological processes (including reproduction, growth, and feeding behavior). It further defines the habitat suitability for different fish species (Çetinkaya, 2003; Emre and Kürüm, 2007). During the study, the mean water temperature across six sampling points was found to be 10.4°C, between -0.3 °C to 20.7 °C (Table 1). These values fall within the optimal range for trout aquaculture (Emre and Kürüm, 2007). According to TS 266/T3 standards, the recommended water temperature for human consumption is 12 °C, with an allowable maximum of 25 °C (TSE, 2022). Other national regulations similarly permit temperatures up to 25 °C for Class I water bodies (WHCR, 2005; SWQR, 2016; QTWDR, 2019), and the data also align with EUDWR and WHO standards (Tebbut, 1998; WHO, 2022; EUDWR, 2023). These findings indicate that the thermal conditions of the stream are generally suitable for both aquatic life and potential domestic uses.

Turbidity

Turbidity, an essential parameter for assessing water suitability for both drinking and aquatic life, showed considerable variability across sampling sites. The highest turbidity value was recorded at the Regulator II point in June, with a peak value of 95.9 NTU and an average of 26.22 NTU (Table 1). Elevated turbidity levels in the region are likely due to erosion caused by sparse vegetation cover, a common issue in semi-arid watersheds.

According to TS 266/T3, maximum permissible turbidity values are 5 NTU for Class I and II waters, and 1 NTU for treated drinking water (TSE, 2022). Based on QTWDR (2019), the water quality falls into the A2 category on average and A3 based on peak values. As such, the water is not suitable for direct use in drinking or aquaculture without prior treatment and disinfection.

While the water may be used in agricultural irrigation without treatment, high turbidity levels may lead to operational issues in modern irrigation systems, such as emitter clogging and reduced efficiency.

Dissolved Oxygen and saturation

Dissolved oxygen (DO) is a key indicator of water quality, particularly significant for drinking water palatability and the sustainability of aquatic life. Its presence not only reflects a well-oxygenated system but also implies the absence of malodorous and potentially toxic gases such as hydrogen sulfide and methane (Çetinkaya, 2003). In waters with low oxygen concentrations, fish may exhibit reduced physiological functions such as feeding, growth, and reproduction, and are often observed congregating near surface layers or water inflows in search of more oxygenated zones (Emre and Kürüm, 2007). In the Bendimahi Stream, the mean dissolved oxygen concentration was measured at 10.86 mg L^{-1}, with values ranging from 4.28 to 21.51 mg L^{-1} and a saturation level averaging 122.9% (Table 1). These values place the stream within the Class I water quality category, indicating high ecological and chemical water quality (Tebbutt, 1998; SWQR, 2016). The high DO levels observed may be attributed to the stream's cold temperature regime and turbulent flow, both of which facilitate greater oxygen solubility and mixing. These conditions are highly favorable for the survival and reproduction of sensitive aquatic species, including those endemic to the Lake Van Basin.

Table 1. Monthly water analysis results obtained from in-situ measurements

Months	Temp. (°C)	Tur (NTU)	DO (mg L^{-1})	OS (%)	pH	Con(µS cm^{-1})	Salinity(‰)
Jan.	3.11	12.89	9.59	92.3	7.90	859.5	0.40
Feb.	4.51	10.61	10.96	100.1	8.18	861.5	0.41
March	7.48	24.84	11.95	136.8	8.11	492.3	0.38
April	15.55	11.17	13.63	174.6	8.11	491.3	0.29
May	15.93	15.42	11.74	149.9	8.20	504.2	0.29
June	17.90	26.22	9.99	131.7	8.10	710.5	0.40
July	16.66	4.68	9.54	122.7	7.68	654.3	0.38
Aug.	16.01	1.92	8.66	111.1	7.50	658.1	0.38
Sept.	12.20	3.07	9.57	113.4	7.74	584.3	0.37
Oct.	7.73	4.32	10.37	108.4	7.76	659.0	0.38
Nov.	6.50	4.58	10.80	110.3	8.02	818.2	0.40
Dec.	1.26	8.64	13.53	123.6	7.90	872.5	0.36
Mean	10.4±6.0	10.7±15.3	10.9±3.8	122.9±47.4	7.9±0.5	680.5±173.3	0.37±0.06
(Min-max.)	(-0.3-20.7)	(0.3-95.9)	(4.3-21.5)	(42.9-276.1)	(7.1-9.6)	(375-981)	(0.2-0.5)

pH

pH plays a crucial role in various physiological processes of aquatic organisms (such as growth, feeding, and stress response) and affects the solubility and toxicity of substances in water Çetinkaya, 2003; Elp, 2024). In this study, the average pH was measured as 7.93 (ranging from 7.12 to 9.63), indicating that the stream is slightly alkaline in nature (Table 1). In general, the optimal pH range for aquaculture is between 6.5 and 9.0 (Çetinkaya, 2003; Emre and Kürüm, 2007), which is also suitable for irrigation purposes. The pH values determined in this study fall within the acceptable ranges for human consumption, irrigation, and fisheries according to both EUDWR (78/659/EEC and SI No. 99 of 2023) and Turkish regulations (Tebbut, 1998; WHCR, 2005; TSE, 2022; SWQR, 2016; QTWDR, 2019; EUDWR, 2023).

Carbonate, Bicarbonate and Alkalinity

In the study, carbonate was not detected in any of the samples, while bicarbonate was determined to be 651.6 mg L^{-1} (ranging from 414.8 to 841.8 mg L^{-1}), and total alkalinity was calculated to as 490.55 mg L^{-1} (ranging from 340 to 690 mg L^{-1}) (Table 2). Alkalinity in water is important for its pH buffering capacity and influences the solubility and toxicity of various elements in drinking water, fisheries, and irrigation waters. The alkalinity levels of the Bendimahi Stream are at the upper limits for rainbow trout farming (Ayers and Westcot, 1994; Tebbut, 1998; Çetinkaya, 2003; Emre and Kürüm, 2007; WHO, 2022).

Chloride, Salinity and Conductivity

Electrical conductivity and salinity, which are particularly important parameters for irrigation, are closely related to the concentration of dissolved solids, ion content, and temperature in water. In freshwater systems, there is a positive correlation between conductivity and biological productivity. However, for irrigation and domestic use, values above a certain threshold are undesirable. If there is a high conductivity in inland water resources, it is thought that a domestic or industrial source of pollutant is mixed into the water (Çetinkaya, 2003;

Ayers and Westcot, 1994; Tebbut, 1998). In Bendimahi stream, the average conductivity was measured at 680.47 µS cm^{-1} (between from 375 to 981 µS cm^{-1}), and salinity at 0.37‰ (between from 0.20 to 0.50‰) (Table 2). These values fall within acceptable limits for human consumption and fisheries and are classified as Class I according to Turkish and EU regulations (Tebbut, 1998; Emre and Kürüm, 2007; WHCR, 2005; TSE, 2022; SWQR, 2016; QTWDR, 2019). According to FAO irrigation water quality guidelines, values between 700-3000 µS cm^{-1} are considered suitable for irrigation purposes (Ayers and Westcot, 1994).

Chloride, one of the primary constituents contributing to seawater salinity, is found in nature either in its ionic form (Cl^-) or as a salt combined with a cation. The presence of chloride in gaseous form in water is generally indicative of contamination from waste inputs (Çetinkaya, 2003). In the Bendimahi Stream, the average chloride concentration was determined to be 11.68 mg L^{-1}, ranging from 7.10 to 21.30 mg L^{-1} (Table 2). From a human health perspective, excessive chloride intake may affect kidney function and plays a role in fluid distribution between intracellular and extracellular compartments, gastric acid production, and hormone transport. The average daily chloride requirement for humans is approximately 2-3 g; deficiencies may lead to digestive disorders and muscle weakness (Atabey, 2015). According to Turkish and EU legislation, the Bendimahi Stream is classified as Class I in terms of water quality for fisheries, drinking water, and irrigation (Tebbut, 1998; WHCR, 2005; TSE, 2022; SWQR, 2016; WHO, 2022; EUDWR, 2023). In drinking water, chloride concentrations above 250 mg L^{-1}may impart a salty taste (WHO, 2022). In irrigation water, chloride is one of the most common causes of toxicity. Since chloride is not retained by the soil, it is absorbed by plants and accumulates in the leaves as it cannot be released through transpiration, potentially leading to leaf burn and desiccation, especially at concentrations between 0.3% and 1.0% (Ayers and Westcot, 1994).

Calcium, Magnesium and Total Hardness

Hardness, which arises primarily from the presence of divalent cations-particularly Ca^{2+} and Mg^{2+} ions-represents an important water quality parameter and is considered essential in waters used for aquaculture. Magnesium and calcium are vital for the skeletal structures of both aquatic and terrestrial organisms. In domestic and industrial waters that are subjected to heating, hardness can lead to problems due to precipitation (Çetinkaya, 2003; Emre and Kürüm, 2007). Additionally, these elements play crucial roles in numerous physiological functions in blood of humans and animals, including blood coagulation, immune system, oxygen transport to cells, muscle contraction, and the transmission of nerve impulses. Deficiencies may lead to symptoms such as cramps, dizziness, arrhythmia, rickets, osteoporosis, and tooth decay (Atabey, 2015).

Table 2. Monthly water analysis results obtained from titrimetric analyses

Months	Cl(mg L^{-1})	Ca(mg L^{-1})	Mg(mg L^{-1})	T.Hard. (mg L^{-1})	HCO_3(mg L^{-1})	T.Alk.(mg L^{-1})
Jan.	12.42	154.13	49.93	428.0	610.0	500.0
Feb.	15.67	157.86	54.47	421.3	638.5	523.3
March	14.20	145.06	56.41	594.7	589.7	483.3
April	11.83	133.33	51.55	545.3	504.3	413.3
May	12.42	139.73	47.01	542.7	504.3	446.7
June	12.09	167.46	59.66	664.0	638.5	523.3
July	10.35	161.06	55.12	629.3	549.08	450.0
Aug.	9.76	163.73	53.49	629.3	601.9	493.3
Sept.	11.83	148.26	55.11	597.3	616.1	505.0
Oct.	8.87	166.93	63.55	673.3	585.6	480.0
Nov.	10.05	172.26	49.61	605.3	717.8	588.3
Dec.	10.65	128.00	50.90	340.0	585.6	480.0
Mean	11.7±3.2	153.2±29.4	53.9±14.9	555.9±128.1	651.6±81.2	490.6±66.6
(Min-max.)	(7.1-21.3)	(80.0-198.4)	(19.5-85.6)	(224-800)	(414.8-841.8)	(340-690)

In irrigation water, excessive calcium uptake can induce chlorosis by limiting the absorption of other nutrients, while high magnesium levels may reduce crop yields (Ayers and Westcot, 1994). In the present study (Table 2), calcium concentration was determined to be 153.15 mg L^{-1} (80-198.9 mg L^{-1}), magnesium 53.9 mg L^{-1} (19.5-85.6 mg L^{-1}), and total hardness was calculated as 555.9 mg L^{-1} (224-800 mg

L^{-1}). Based on these values, the Bendimahi Stream is classified as having very hard water. Neither EU nor Turkish regulations impose specific limits on calcium, magnesium, or total hardness in water; however, the Turkish Standards (TS 266/T3) specify upper limits of 200 mg L^{-1} for calcium, 50 mg $L^{-1}$for magnesium, and 50 French degrees (500 mg L^{-1}) for total hardness (TSE, 2022).

Nitrogen Compounds in Water

Nitrogenous compounds in water, which serve both as nutrients and as indicators of pollution, were measured with the following average concentrations: NO_3 2.0 mg L^{-1} (0-7.8 mg L^{-1}), NO_2 0.018 mg L^{-1} (0.002-0.061 mg L^{-1}), NH_3 0.06 mg L^{-1} (0.01-0.018 mg L^{-1}), and NH_4 0.06 mg L^{-1}(0.01-0.019 mg L^{-1}) (Table 3). Although nitrogen is an essential plant nutrient that promotes growth, concentrations exceeding 30 mg L^{-1}can cause problems in irrigation water. Total NO_2 and NO_3 nitrogen above 100 mg L^{-1} or NO_2 alone above 10 mg L^{-1}may have toxic effects on plants (Ayers and Westcot, 1994). Nitrate, in particular, promotes the proliferation of algae and aquatic plants, triggering eutrophication and leading to oxygen deficiency. In drinking water, nitrate levels above 50 mg L^{-1} and nitrite levels above 3 mg L^{-1} may cause methemoglobinemia (blue baby syndrome) and thyroid dysfunction, especially in infants. Nitrite should not be present at all in drinking or aquaculture waters (Çetinkaya, 2003; WHO, 2022).

The presence of ammonia in water is often an indicator of sewage or animal waste contamination. Ammonia levels above 0.05 mg L^{-1} is a sign of pollution. In humans, ingestion of more than 200 mg/kg body weight can be toxic. In drinking water, ammonia reduces disinfection efficiency and contributes to nitrite formation, as well as taste and odor problems. While the ammonium ion (NH_4) is not significantly toxic to aquatic organisms, free ammonia (NH_3) can be harmful even at low concentrations (Çetinkaya, 2003; Emre and Kürüm, 2007; Atabey, 2015; WHO, 2022). The nitrate, nitrite, and ammonia values obtained from the Bendimahi Stream fall within the acceptable lower limits for drinking, irrigation, and aquaculture purposes, and correspond to Class I water quality as defined by Turkish and EU regulations (Tebbutt, 1998; WHCR, 2005; TSE, 2022; SWQR, 2016; QTWDR, 2019; WHO, 2022; EUDWR, 2023).

Phosphorus

Phosphorus is the most important nutrient mineral in natural waters in terms of productivity and plays a limiting role in the growth of organisms. It is the primary element driving eutrophication (Harper 1992). Phosphorus is found in fish, meat, eggs, milk, wheat, barley, corn, legumes, nuts, walnuts, potatoes, and cheese. It plays a key role in fundamental physiological functions by being a structural component of bones, phospholipids, nucleic acids, enzymes, hormones, and proteins (Atabey, 2015). In this study, phosphate and total phosphorus concentrations were determined as 0.2 mg L^{-1} (0.03-0.6 mg L^{-1}) and 0.09 mg L^{-1} (0.01-0.031 mg L^{-1}), respectively (Table 3). Ayers and Westcot (1994) reported that phosphate concentrations up to 2 mg L^{-1} are acceptable for irrigation purposes. According to both EU and Turkish regulations, the phosphorus and phosphate levels detected in this study fall within the limits specified for Class I waters in terms of drinking, irrigation, and aquaculture water quality (Tebbutt, 1998; TSE, 2022; SWQR, 2016; EUDWR, 2023).

Sulphate

Sulphate, which imparts a bitter taste when present in high concentrations and may cause diarrhea at elevated levels, is not known to have other significant adverse health effects (WHO, 2022). According to Turkish, WHO, and EU drinking water regulations, concentrations above 250 mg L^{-1} are considered the upper limit (Tebbutt, 1998; WHCR, 2005; TSE, 2022; WHO, 2022; EUDWR, 2023). In the present Sulphate levels can be elevated in regions with volcanic origin (Çetinkaya, 2003). study, the sulfate concentration was found to be 8.6 mg L^{-1} (2-21 mg L^{-1}) (Table 3). The source of the Bendimahi Stream, Kaz Lake, is located at the foot of Tendürek Mountain, a volcanic mountain. Despite this, the sulfate values obtained in this study were not high.

Potassium

Potassium, a plant nutrient element, is typically found in natural waters at concentrations ranging from 1 to 10 mg L^{-1} (Mutlu et al., 2013). In the Bendimahi Stream, the average potassium concentration was found to be 6.7 mg L^{-1} (3.7-14.9 mg L^{-1}), (Table 3). No health-based guideline value has been established; however, concentrations above 200 mg L^{-1} may impart a salty taste. Potassium is widely used in agriculture for fertilizer production, as well as in the chemical, food, ceramic, soap, detergent, glass, paint, and pharmaceutical industries. It is found in many animal products, vegetables, grains, and fruits. The daily requirement for an adult ranges from 2 to 4 grams. Potassium plays a key role in water regulation in the body, stimulation of nerve and muscle function, heart rhythm, blood pressure, and protein synthesis (Atabey 2015). According to TS 266/T3, concentrations up to 12 mg L^{-1} are permissible (TSE, 2022).

Fluoride

Fluoride, which is known to be widespread in the Bendimahi Basin and is used in various industrial sectors and found in many food items besides water, is highly important for skeletal structures in the human body, particularly the teeth. The daily requirement ranges from 1 to 4 mg. Deficiency can lead to tooth decay and bone demineralization, while excess intake may cause irreversible dental and skeletal fluorosis, disability, or even death. Similar effects are observed in animals (Atabey 2015; Tebbut, 1998; WHO, 2022). In the Bendimahi Stream (Table 4), the average fluoride concentration was found to be 1.74 mg L^{-1} (0.29-4.90 mg L^{-1}). According to Turkish, EU, and WHO standards, the limit value is 1.5 mg L^{-1} (Tebbut, 1998; WHCR, 2005; TSE, 2022; SWQR, 2016; QTWDR, 2019; WHO, 2022; EUDWR, 2023). Since the fluoride concentration in the Bendimahi Stream exceeds this limit, it is classified as Class II water according to the annual average value based on the SWQR (2016) standards.

Table 3. Monthly water analysis results obtained from spectrophotometric analyses 1

Months	NO_3^-(mg L^{-1})	NO_2(µg L^{-1})	NH_4(µg L^{-1})	NH_3(µg L^{-1})	PO_4^-((µg L^{-1})	P(µg L^{-1})	SO_4^-(mg L^{-1})	K(mg L^{-1})
Jan.	4.28	10	50	50	80	20	5.0	8.6
Feb.	2.38	10	50	50	180	30	3.2	8.7
March	1.43	18	90	90	280	40	11.5	5.8
April	0.33	17	80	80	430	30	9.3	5.7
May	1.11	16	80	80	270	50	8.0	5.5
June	2.35	26	130	90	170	50	10.5	6.3
July	1.65	14	70	70	110	50	10.6	5.83
Aug.	1.98	14	60	60	150	140	9.8	6.2
Sept.	1.83	14	70	60	120	130	9.3	6.1
Oct.	2.53	30	20	20	150	160	9.3	6.2
Nov.	1.58	32	40	40	280	250	10.8	6.5
Dec.	2.61	14	40	40	230	130	6.0	9.4
Mean	2.0±1.4	18±11	60±40	60±40	200±130	90±70	8.6±3.3	6.7±1.8
(Min-max)	(0-7.8)	(2-61)	(10-190)	(10-180)	(30-600)	(10-310)	(2-21)	(3.7-14.9)

Metals in Bendimahi Stream

Copper is both an essential plant nutrient and a potential polluting in water. Even at low concentrations, it can exert toxic effects on aquatic plants and fish; however, its toxicity decreases with increasing water hardness (Çetinkaya, 2003; WHO, 2022). Copper is found in liver, fish, shellfish, leafy vegetables, walnuts, rye, beans, peas, lentils, hazelnuts, peanuts, and mushrooms. The daily requirement for an adult human is approximately 2-4 mg. It is a component of hemoglobin and plays a role in the regulation of heart and enzyme functions, red blood cell production, metabolic activities, and the immune system. Excess copper intake can lead to arteriosclerosis and cataracts, while deficiency may cause anemia, immune dysfunction, and eczema. When present in water at concentrations above 5-10 mg L^{-1} , copper can cause taste and odor issues as well as diarrhea in children (Atabey, 2015; WHO, 2022). In the Bendimahi Stream, the copper concentration was measured at 0.0085 mg L^{-1} (0.004-0.012 mg L^{-1}) (Table 4). According to Ayers and Westcot (1994), the recommended limit for irrigation water is 0.2 mg L^{-1} , with values above 1 mg L^{-1} potentially toxic to many plants and concentrations exceeding 0.5 mg L^{-1} harmful to animals. The EU Directive 74/464/EEC sets the upper limit for drinking water at 0.02 mg L^{-1} for class I waters and 0.01 mg L^{-1} for fisheries (Tebbut, 1998). Turkish regulations specify acceptable values ranging from 0.02 to 3 mg L^{-1} (WHCR, 2005; TSE, 2022; SWQR, 2016; QTWDR, 2019; EUDWR, 2023).

Aluminum, widely used in industries such as aircraft and food production, and drinking water treatment, was detected at a concentration of 4.26 µg L^{-1} (0-30 µg L^{-1}) in the Bendimahi Stream (Table 4). In excessive amounts, aluminum imparts a turbid bluish appearance to water. It has be en reported to have toxic effects and may contribute to Alzheimer's disease, as well as impact the respiratory, nervous, and digestive systems (Tebbut, 1998; WHO, 2022). Atabey (2015) indicated that the maximum permissible level of aluminum in drinking water is 200 µg L^{-1} . For irrigation and livestock drinking water, a maximum limit of 5000 µg L^{-1} has been recommended (Ayers and Westcot, 1994). The EU directives for drinking and fisheries waters do not specify a limit for aluminum (Tebbut, 1998; EUDWR, 2023). According to Turkish regulations, the allowable concentration ranges between 200 and 2000 µg L^{-1} (WHCR, 2005; TSE, 2022; SWQR, 2016; QTWDR, 2019), and the Bendimahi Stream is classified as Class I in this regard.

Iron, found in a wide range of foods such as red meat, seafood, eggs, cereals, vegetables, fruits, and nuts, is an essential nutrient that can cause various health issues when deficient or in excess. It plays a crucial role in the structure of hemoglobin in the blood. The daily iron requirement for humans is approximately 10-18 mg. Iron deficiency may lead to fatigue, shortness of breath, jaundice, headaches, anemia, sleep disturbances, brittle nails, and hair loss, while excessive intake can cause liver failure, stomach cramps, dizziness, vomiting, and even coma. The lethal dose is estimated to be around 200-250 mg per kg of body weight (Atabey, 2015). Iron is not toxic in well-aerated soils; however, it can acidify the soil and reduce the availability of phosphorus and molybdenum. The maximum acceptable level for irrigation water is 5 mg L^{-1}, while no upper limit is defined for livestock drinking water (Ayers and Westcot, 1994). In the Bendimahi Stream, total iron was determined to be 0.025 mg L^{-1}(0-0.19 mg L^{-1}) (Table 4). WHO does not specify a maximum limit for iron in drinking water (WHO, 2022), whereas the EU directive states a limit of 0.2 mg $L^{-1}$for Class I waters, with a maximum allowable concentration of 2 mg L^{-1}(Tebbut, 1998; WHCR, 2005; TSE, 2022; SWQR, 2016; QTWDR, 2019; WHO, 2022; EUDWR, 2023). According to Turkish regulations, while no limit is specified in WHCR (2005), TS 266/T3 sets the upper limit at 0.2 mg L^{-1}(TSE, 2022), and other regulations specify 0.3 mg L^{-1} for Class I waters, with an overall maximum limit of 5 mg L^{-1}(SWQR, 2016; QTWDR, 2019).

Zinc is found in meat, seafood, eggs, cereals, walnuts, hazelnuts, and legumes. The daily requirement for humans ranges from 6 to 15 mg. Zinc deficiency can result in weakness, dwarfism, skin rashes, diarrhea, loss of appetite, immune deficiency, learning difficulties, hair loss, and delayed wound healing. Excess intake, on the other hand, may lead to vascular disorders, eczema, constipation, and other issues (Atabey, 2015). In this study (Table 4), zinc was measured at 0.17 mg L^{-1} (0.01-0.28 mg L^{-1}). Concentrations above 4 mg L^{-1} can impart an astringent taste to water, and levels exceeding 3 mg L^{-1} in drinking water are considered undesirable (WHO, 2022). The EU Drinking Water Directive sets a range of 0.5-3 mg L^{-1} for Class I waters and a maximum of 0.5 mg L^{-1} for waters intended for fisheries (EUDWR, 2023). In Turkish regulations, WHCR (2005) does not specify a limit, whereas TS 266/T3 and other standards provide values ranging from 0.2 to 3 mg L^{-1} (TSE, 2022; SWQR, 2016; QTWDR, 2019).

Chromium is found in black tea, cocoa, honey, hazelnuts, walnuts, grains, cheese, meat, and mushrooms. The daily requirement for humans is approximately 150-200 µg. It plays a role in the transport of glucose into cells and in carbohydrate metabolism. Chromium deficiency can lead to high cholesterol, fatigue, and irritability. Hexavalent chromium (Cr^{6+}) is toxic and carcinogenic. It accumulates in the lungs, liver, spleen, kidneys, and bones, and is excreted through urine. Ingestion of 1-5 g of chromate can cause acute poisoning symptoms such as gastrointestinal disturbances, palpitations, and abdominal cramps; prolonged and high-level exposure may lead to weight loss, dizziness, irritation and burning in the nose, eyes, and throat, coughing, chest pain, asthma, and cancer (Atabey 2015; WHO, 2022). In the Bendimahi Stream (Table 4), chromium was measured at 11 µg L^{-1} (3-27 µg L^{-1}). According to the EU Drinking Water Directive and WHO, the maximum permissible level is 50 µg L^{-1}, and for fisheries, the acceptable range is 5-250 µg L^{-1} (Tebbut, 1998; WHO, 2022; EUDWR, 2023). Turkish regulations state that Cr^{6+} should not be present in drinking and irrigation waters, and the total chromium concentration should not exceed 20 µg L^{-1} (Tebbut, 1998; WHCR, 2005; TSE, 2022; SWQR, 2016; QTWDR, 2019). Ayers and Westcot (1994) reported that up to 100 µg L^{-1} is permissible in irrigation water and up to 1000 µg L^{-1} for livestock drinking water.

Manganese, which is abundantly present in many food items and the Earth's crust, precipitates as a black residue when oxidized and causes unpleasant taste and gray-black stains when used in industries such as laundry, dishwashing, plumbing fixtures, paper, leather, textiles, plastics, and food. It is utilized in many industrial applications and is one of the essential elements for enzyme function. In water, concentrations above 0.5 mg L^{-1} produce an unpleasant taste. Excessive manganese intake can lead to acute manganese poisoning and motor disorders resembling Parkinson's disease. It can be removed from water through oxidation and filtration (Atabey, 2015; WHO, 2022). In the Bendimahi Stream

(Table 4), manganese concentration was measured at 252.5 µg L^{-1} (range: 0–900 µg L^{-1}). According to drinking water guidelines, the WHO limit is 80 µg L^{-1} (WHO, 2022), the EU standard for Class I waters is 50 µg L^{-1} (Tebbut, 1998; EUDWR, 2023), and Turkish standards set a maximum of 20 µg L^{-1} for high-quality waters, with an acceptable upper limit of 50 µg L^{-1} (WHCR, 2005; TSE, 2022). For water intended for drinking water production, the limits are 200 and 1000 µg L^{-1} (QTWDR, 2019). In terms of pollution classification, Classes I, II, III, and IV are defined with respective limits of 100, 500, 3000, and >3000 µg L^{-1} (SWQR, 2016). The permissible limits are 200 µg L^{-1} for irrigation water and 50 µg L^{-1} for livestock drinking water (Ayers and Westcot, 1994). Considering all these standards, the manganese concentration in the Bendimahi Stream exceeds the acceptable upper limits. Therefore, water from this source should undergo effective filtration and oxidation before use.

Table 4. Monthly water analysis results obtained from spectrophotometric analyses 2

Months	Cu(µg L^{-1})	Al(µg L^{-1})	Fe^{+2}(µg L^{-1})	Zn(µg L^{-1})	Cr^{+6}(µg L^{-1})	Mn(µg L^{-1})	F (mg L^{-1})	CN^{-}(µg L^{-1}
Jan.	8.5	1.66	10	170	19	550	4.37	0.6
Feb.	8.6	1.66	16	130	11	260	2.01	1.5
March	8.0	2.00	11	220	11	280	1.26	1.8
April	8.2	1.00	20	180	12	160	1.11	1.6
May	8.0	13.66	23	180	12	110	0.62	1.3
June	9.3	6.16	61	150	10	60	1.30	4.1
July	7.5	9.66	18	170	8	150	1.09	1.1
Aug.	10.0	4.50	10	180	8	80	1.79	1.0
Sept.	9.0	3.66	23	180	11	210	1.54	1.5
Oct.	8.8	3.50	40	150	10	310	1.32	3.0
Nov.	7.8	2.33	65	200	9	230	1.25	2.0
Dec.	8.8	1.33	11	100	12	630	3.18	0.5
Mean	8.5±1.6	4.26±5.33	25±34	170±50	11±5	252.5±177	1.7±1.1	1.6±1.6
(Min-max)	(4-12)	(0-30)	(0-190)	(90-280)	(3-27)	(0-900)	(0.29-4.9)	(0-9)

Cyanide, a highly toxic substance, is widely used in various industrial sectors. It can also be found in approximately 800 plant species (such as apples, peaches, apricots, cherries, and plums), in cigarette smoke, and may be produced by animals, fungi, and microorganisms. The most sensitive organs in cyanide poisoning are the central nervous system and the heart. Symptoms of cyanide poisoning include excessive foamy salivation, vomiting, irregular heartbeat, redness of the skin and mucous membranes, headache, visual disturbances, hormonal imbalances, tremors, respiratory difficulty, loss of consciousness, bleeding from the mouth and nose, coma, and death (Renklidağ and Karaman, 2003; Özdemir and Sırıken, 2006; WHO, 2022; Atabey, 2024). In the Bendimahi Stream, the average cyanide concentration was determined as 1.6 µg L^{-1} (ranging from 0.0 to 9.0 µg L^{-1}) (Table 4). According to the Turkish Food Codex, the maximum allowable level of cyanide in drinking water is 0.01 mg L^{-1} (Özdemir and Sırıken, 2006), while Turkish and EU regulations set the limit at 50 µg L^{-1} (Tebbut, 1998; WHCR, 2005; SWQR, 2016; QTWDR, 2019; EUDWR, 2023). Based on these standards, the cyanide levels in the Bendimahi Stream do not pose a concern and fall within the Class I water quality category.

Conclusions

The Bendimahi Stream is used locally for drinking and domestic water supply, livestock watering, agricultural irrigation, and fisheries. In terms of drinking water quality, the stream falls into Class I for parameters such as temperature, DO, OS, chloride, nitrate, nitrite, sulfate, potassium, copper, aluminum, total iron, zinc, and cyanide; Class II for ammonium-ammonia, pH, chromium, fluoride, and phosphorus; and Class III for manganese.

According to the study results, if the Bendimahi Stream is to be used for drinking water, domestic purposes, agricultural irrigation, and fisheries in Muradiye, Çaldıran, and nearby areas, effective treatment should be applied, particularly for ammonia, phosphorus, fluoride, manganese, and chromium.

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Declaration of interests

The authors declare that they have no conflict of interest.

Author Contributions

ÖBB: Conducted all sampling and laboratory analysis and wrote the thesis. FŞ: Wrote, revised, edited the manuscript and supervisior of the thesis.

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