

A PHYSICAL, CHEMICAL AND MICROBIOLOGICAL EVALUATION OF KARACADAĞ NATURAL SPRING WATERS

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Abstract. This study includes studies to determine water quality by examining the pollution level, interbasin spread, seasonal changes in physical, chemical and microbiological properties of natural spring waters of Karacadağ, Diyarbakır province and the interaction of natural spring water with pollutant sources. Periodic analyses were conducted on water samples in the field and in the laboratory in the study area. Based on the findings obtained as a result of the analyses, the evaluation of natural spring waters for drinking, agricultural and industrial use was made and the causes of pollution of natural water resources were revealed. The investigation revealed a statistically significant correlation between pH and electrical conductivity (EC) values in the natural spring waters of Karacadağ. The link was identified in 43.7% of the samples. The correlation between pH and EC values in natural spring waters serves as a significant indicator for assessing the chemical characteristics and contamination levels of the water. Microbiological analyses conducted on natural spring waters in the Karacadağ region showed that high loads in indicator organisms such as fecal streptococci and coliform bacteria put the waters at risk of fecal contamination and therefore their use as drinking water poses serious risks to public health. The data obtained show that the microbiological quality standards determined by Turkish Standards, the World Health Organization and the European Union are exceeded and therefore the microbiological safety of the waters cannot be ensured.

Keywords: *Microbiological safety, natural spring waters, physical, chemical and microbiological properties.*

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Received: 17 January 2025;

Accepted: 5 March 2025;

Published: 15 April 2025.

1. Introduction

Rapidly increasing population, industrialization and urbanization processes negatively affect the quality of natural water resources and constitute a significant environmental problem. Pollutants resulting from anthropogenic activities reach underground water basins and disrupt the natural balance and functions of these systems. Chemicals used in agricultural activities, industrial wastes and domestic wastewater are among the main causes of underground water pollution. Changes in the physical, chemical and biological properties of underground water limit the suitability of this resource for various purposes.

In developed countries, extensive research is being conducted on both surface water and groundwater for the purpose of sustainable use and protection of water resources. In

How to cite (APA):

Tumur, S. (2025). A physical, chemical and microbiological evaluation of Karacadağ natural spring waters. *Advances in Biology & Earth Sciences*, 10(1), 63-87 <https://doi.org/10.62476/abes.10163>

these countries, groundwater research goes beyond quantitative analysis and focuses on issues such as water quality, pollution sources and remediation methods (Freeze & Cherry, 1979).

The protection and sustainable use of groundwater resources are at the heart of water management policies of developed countries. Determination of groundwater quality and monitoring of changes over time are among the main objectives of these studies. The effects of anthropogenic and natural pollutants on groundwater and the long-term consequences of these effects are examined in detailed.

Different technologies and methods are being developed and implemented for cleaning and rehabilitating polluted groundwater. Integrated management plans are being created for the protection of groundwater basins and various measures are being taken within the framework of these plans.

In this study, the quality and pollution status of natural spring waters in the Karacadağ region of Diyarbakır province were examined on samples taken in different seasons.

The analysis results of the physical, chemical and microbiological contents of the spring waters in the Karacadağ region; the effects of pollutant sources and geological and hydrogeological characteristics of the basins on pollution were evaluated. The karst structure of the basin causes rapid pollution of spring waters and the spread of pollutants in a short time. Climate change, changes in the precipitation regime and increased evaporation have negative effects on the quantity and quality of spring water. The analysis methods used in this study and the results obtained will make significant contributions to the development of spring water management and protection strategies. Long-term monitoring of spring waters will help to better understand the effects of climate change on spring water quality. The results obtained show that urgent measures should be taken to protect groundwater resources in the region. Actions such as establishing artificial recharge systems to address diminishing water tables, designating protected zones around resources to mitigate pollution concerns and advocating for sustainable agriculture methods to decrease chemical inputs can be undertaken.

In future studies, the effects of different pollutants on groundwater quality and the long-term consequences of these effects can be examined in more detail.

2. Literature Study

Groundwater is formed as a result of the downward movement of rainwater under the effect of gravity in the soil profile and the formation of a saturated zone. These waters are accessed through wells, natural springs and horizontal drainage systems. Groundwater has a richer mineral content than surface waters by taking various minerals into solution during the soil-water interaction process. The presence of a sufficiently thick percolation medium in deep aquifers ensures microbiological purification of groundwater. However, groundwater may be exposed to chemical pollution as a result of the infiltration of surface pollutants. It takes a long time to eliminate such pollution and in some cases, it may not be possible to completely eliminate it (Bora, 2016).

Environmental pollution, which has emerged with the rapid advancement of industrialization, poses a serious threat on a global scale today. Rapid population growth, industrialization and unplanned urbanization processes have significantly increased the pressure on water resources due to the increasing waste load. Industrialization and population growth on a global scale have made environmental pollution one of the most

important problems. Unplanned urbanization and increased waste production in particular pose a serious risk to the sustainability of water resources (Altun, 2011).

Ca and Mg ions in solution tend to enter into precipitation reactions with carbonate and bicarbonate ions. However, if there is an excess of bicarbonate ions in the system, they combine with sodium ions to form the sodium bicarbonate compound, which increases the sodium ion concentration in the environment and increases the potential harmful effects (Dorak *et al.*, 2019).

Water analysis results showed that the chlorine concentration was above the standards and turbidity values were high from time to time. In microbiological analysis, it was determined that the total mesophilic aerobic bacteria count was higher than the total coliform bacteria count and also that the total coliform bacteria count was higher than the fecal coliform bacteria count (Mahmut, 2014).

In the study, 19 wells located within the borders of Bursa province and whose research studies are ongoing by the DSI 1st Regional Directorate are included in the scope of the examination. The results of the physical, chemical and bacteriological analyses conducted between 1990-1999 in these 19 wells were evaluated and the existing groundwater pollution potential was tried to be determined (Durmaz, 2001).

Bacteriological and chemical analysis results of 95 water samples taken in a one-year period show that water quality is generally not in compliance with standards. Microbiological pollution has become evident, especially with the presence of coliform and fecal coliform bacteria. In chemical analyses, it was determined that free chlorine levels were in violation of regulations (Gültekin, 2015).

It was determined that water samples taken from Lake Bafa and its channels were not suitable for use as irrigation water due to high sodium and chloride concentrations. In addition, the high levels of trace elements and nitrogen compounds detected in these waters indicate that the water quality is low and may have negative effects on the ecosystem. The dominance of calcium and bicarbonate ions in stream and well waters in these regions can be evaluated as a result of interaction with carbonate rocks. It can be said that groundwater taken from shallow wells is generally of high quality and complies with drinking water standards. However, some parameters (e.g. ammonium, some heavy metals) were occasionally exceeded (Davraz & Yıldız, 2023).

Drought, temperature increase and rainfall irregularities caused by climate change increase the pressure on water resources and increase the risk of water scarcity. These effects are expected to be felt more severely, especially in the Mediterranean Region. Water consumption of the agricultural sector constitutes a large part of the total water consumption in our country. This situation reveals the necessity of increasing water efficiency in agriculture and taking water saving measures. Various measures such as effective use of water, expansion of wastewater treatment facilities, protection of water structures and basins should be taken for the protection and sustainable use of existing water resources (Çil, 2017).

Pollutants are examined in three main groups according to the nature of the substances: physical, chemical and biological. While physical pollutants include particles suspended in water and water temperature, chemical pollutants cover a wider range of substances such as harmful metals, radioactive substances and various chemicals. Biological pollutants are generally disease-causing microorganisms. The main causes of groundwater pollution are divided into two as natural and human-induced factors. This pollution varies depending on geographical location and human activities (Soyaslan, 2022).

3. Material and Methods

3.1. Material

In the physical analysis of well waters; temperature (T), electrical conductivity (EC), pH, turbidity and color values were determined using thermometer, conductivity meter, pH meter, turbidimeter and colorimeter, respectively.

Chemical analyses were performed using gravimetric, titrimetric, Bruker Aurora M-90 ICP-MS device model inductively coupled mass spectrometer ICP-MS and Perkin-Elmer OPTIMA 5300 ICP-OES model inductively coupled optical emission spectrometer. The presence of metals in high concentrations was determined using UNICAM 929 model atomic absorption spectrometer.

Analyses and calculations were made using the book *Drinking Water Standards* (TSE, 1986) and *Water and Wastewater Analyses*.

In laboratory studies, Oil, Detergent, Cu, NO₂-N, NO₃-N values were measured with a Cary-60 spectrophotometer. PCR TUM50 colorimeter was used for turbidity. HI 98303 device was used for conductivity (EC) measurement.

Glass electrode HANNA HI-2211 7000 seven multi brand pH meter was used for pH adjustments of solutions used in experiments. At the same time, the temperature of the water samples taken was also measured with this device.

ALC-4235 a brand centrifuge device was used for centrifugation steps of solutions in co-precipitation experiments.

The membrane filter technique is a method based on holding a certain volume of water sample on a porous membrane and incubating it in a suitable medium, thus counting the microorganisms present in the water by forming colonies. In this method, membranes with a pore diameter of 0.45 microns are often preferred and incubation is usually carried out at 44°C. The morphological characteristics of the colonies formed allow the identification of bacterial species according to factors such as the medium used and the incubation period.

In drinking water analysis, the membrane filtration method is widely used to determine the microorganism load. In this method, the water sample is passed over a bacteria-holding membrane and the microorganisms on the membrane are brought into contact with the medium and incubated. The colonies formed are examined under a microscope, their types are determined and counted to obtain information about the microbiological quality of the water.

4. General Characteristics of the Study Area

The spring waters of the Karacadağ basin located in Diyarbakır province are at the center of geological and hydrogeological research. In this study, the geological and hydrogeological structure of the basin was revealed with different scale maps and detailed field studies. The data obtained about the natural geographical features of the region, climatic conditions, geological units and the distribution of groundwater resources provide important information about the potential and management of the basin's water resources. In addition, water quality was evaluated with physical, chemical and microbiological analyses of water samples and the necessary measures for the sustainable use of the basin's water resources were tried to be determined.

4.1. Natural Geography

Diyarbakır province is an important geographical unit located in the Southeastern Anatolia Region of Turkey and spread over a wide area of 15,354 km². The city center is located at approximately 37° 55' north latitude and 40° 15' east longitude coordinates (Figure 1) (Harita Genel Müdürlüğü, 2024). In terms of its geographical location, it is adjacent to Siirt and Muş to the east, Şanlıurfa, Adıyaman and Malatya to the west, Bingöl and Elazığ to the north and Mardin to the south.

Diyarbakır province is established on a plain located west of the Tigris River, approximately 650 meters above sea level. Surrounded by high mountains and hills, this geographical structure offers Diyarbakır a unique natural landscape. The hydrographic structure of the province, whose northern borders are determined by the Southeastern Taurus Mountains, is shaped by the Tigris River and its tributaries. The Tigris River flows in a northwest-southeast direction and is fed by important tributaries such as Ambar, Pamuk, Ballıkaya, Olucak, Göksu, Savur and Batman. The Ergani, Diyarbakır, Göksu-Çınar, Seyhan and Batman-Silvan plains located within the provincial borders are important areas in terms of agriculture and settlement.

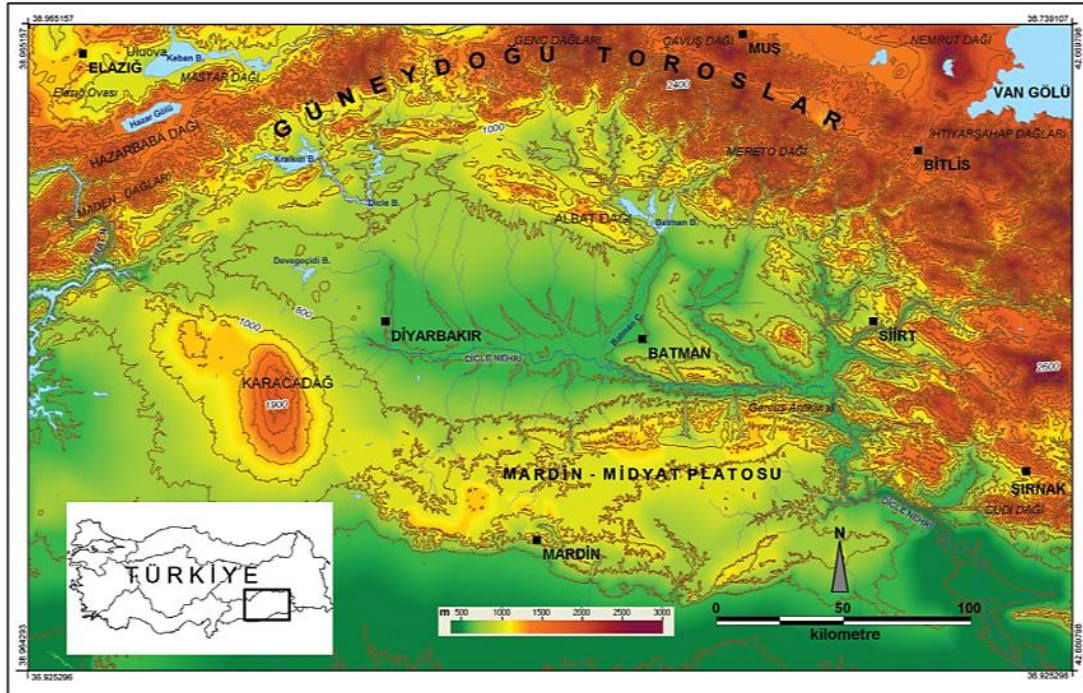


Figure 1. Map of Karacadağ region

4.2. General Climate Characteristics

Diyarbakır province is an important settlement reflecting the characteristic climate conditions of the Southeastern Anatolia Region. The precipitation regime in the region is under the influence of Mediterranean air masses and increases especially in winter and spring. In this study, meteorological parameters such as precipitation, temperature, wind and humidity of Diyarbakır province were evaluated based on the data obtained from observations made over many years. In particular, the precipitation regime of the dam

basins that feed the drinking and utility water resources in the province was analyzed with statistical methods.

In the dam basins of Diyarbakır province and its surroundings, frontal type precipitation is observed in the winter and spring months due to the effect of Mediterranean air masses. The annual average precipitation amounts of the Ambar, Hani and Dankıran dam basins were calculated as 789 mm, 1017 mm and 701 mm, respectively. These results show that there are differences in precipitation distribution depending on the different geographical locations and topographic features of the basins. The average precipitation values between 2000-2020 provide more detailed information about the general precipitation regime of Diyarbakır province.

Summer months are quite hot in Diyarbakır due to the blocking of cool northern winds by the Southeastern Taurus Mountains. In July and August, Diyarbakır, one of the hottest cities in Turkey, has an annual average of 15.9°C, the highest temperature is 46.2 °C and the lowest temperature is -24.2°C according to the long-term average. These values show that the region has a hot and dry climate. However, the influence of warm air masses of Mediterranean origin cannot be ignored.

Wind observations made in Diyarbakır provide important information about maximum wind speeds and directions. Wind speeds and directions are important factors affecting air movements and climatic conditions in the region. Relative humidity measurements provide information about the humidity of the air and have an important effect on the temperature felt especially in the summer months.

Table 1. Average climate data for Diyarbakır province for the years 1929-2023

DIYARBAKIR	January	February	March	April	May	June
Average Temperature (°C)	2.1	3.9	8.7	13.5	18.9	26.3
Average Highest Temperature (°C)	7.3	9.6	15.0	20.5	26.8	34.4
Average Lowest Temperature (°C)	-2.0	-1.1	2.6	6.6	10.9	16.8
Average Sunbathing Time (hours)	4.0	4.8	5.6	7.0	9.1	11.6
Average Number of Rainy Days	10.93	11.27	11.13	11.60	9.47	2.90
Monthly Total Rainfall Average (mm)	63.6	66.8	67.5	63.1	50.0	10.8

Table 2. Average climate data for Diyarbakır province for the years 1929-2023

DIYARBAKIR	July	August	September	October	November	December	Annual
Average Temperature (°C)	31.0	30.5	25.0	17.8	9.3	3.8	15.9
Average Highest Temperature (°C)	38.9	38.7	33.4	25.7	16.3	9.2	23.0
Average Lowest Temperature (°C)	21.7	21.2	15.9	10.4	3.8	-0.5	8.9
Average Sunbathing Time (hours)	11.7	11.0	9.3	7.1	5.5	3.7	7.5
Average Number of Rainy Days	0.40	0.23	1.37	5.83	7.43	11.33	83.9
Monthly Total Rainfall Average (mm)	1.0	0.4	8.4	37.3	54.3	75.3	498.5

4.3. Geological Formation

The Karacadağ volcanics developed on the northern border of the Arabian plate in relation to the neotectonic movement of Anatolia. Karacadağ, located on the Arabian autochthones in Southeastern Anatolia, has been the scene of volcanic activity from the Pliocene to the Quaternary (Figure 2) (Maden Tetkik ve Arama Genel Müdürlüğü, 2020).

The Karacadağ volcanics are mostly derived from basaltic magmas of mantle origin. Massive rocks such as olivine basalt and ogite basalt dominate these volcanics. The fact that the rocks have a porphyritic texture and contain calcite inclusions provides important information about the formation conditions. Although they sometimes show tholeiitic or alkaline properties, they are generally basaltic in character.

The Karacadağ volcanics were formed under the influence of stresses on the Arabian plate in the compression environment that developed as a result of the collision of the Arabian and Anatolian plates. The continent-continent collision, which started in the Middle Miocene, caused the formation of N-S oriented fracture systems in the Karacadağ region and the rise of mantle material to the surface along these fractures. This volcanism is related to the impactogenic rifting that developed during the compression phase after the collision.

Karacadağ volcanics are derived from magmas that are generally basaltic in composition and originate from the mantle. These volcanics can be defined as characteristic plateau basalts that spread by covering young sediments. Being mantle-originated indicates that volcanics are generally formed by melting at high temperatures and low oxygen fugacity.

Karacadağ basalts are characterized by a distinct block structure on the surface and their interphase baked clay and pyroclastic material content increases with the transition to depth. Dark gray-black color, hardness, strength and durability are among the typical physical properties of these rocks. Basalts, which are resistant to hammer blows, generally exhibit planar fracture surfaces.

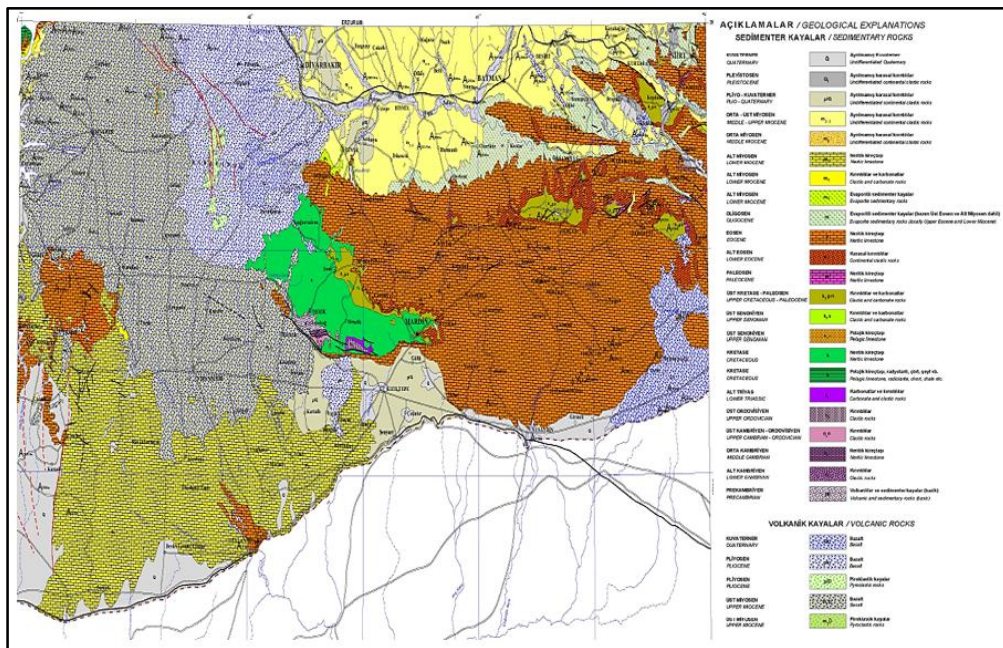


Figure 2. Geological map of Karacadağ region

The cracks, fractures and individual cavities observed in the rock bear the traces of stresses and gas bubbles formed during volcanic activity. The fact that basalts occasionally have a slag appearance indicates a porous texture formed during the rapid cooling of lava and the escape of gases. The presence of interphase baked clay and pyroclastic materials is the result of the re-deposition of particles thrown into the air during volcanic eruptions.

The massive appearance of basalts towards the base indicates that slower cooling and crystallization conditions prevailed in the lower parts of the lava flows. Textural and mineralogical features in the rock provide important information about the physical and chemical conditions in the formation environment.

4.4. Hydrogeology and Water Chemistry of the Study Area

Karacadağ basalts function as an effective aquifer by creating a porous and permeable environment with a developed fracture-crack system. A complex underground water system has developed in the region together with the Şelmo formation. The thinning of the basalts in the east creates a hydraulic gradient, causing the groundwater to move eastward and the formation of springs.

The hydrodynamic properties of basalts determine the speed and direction of water movement in the rock. The quality of the water stored in basalts is affected by the mineralogical structure of the rocks and environmental factors. The increasing water demand in the region may cause the aquifer to be overexploited and the water level to fall.

Karacadağ basalts play an important role in meeting the water needs of the region by hosting high-flow resources. Resources such as Gözeli, İçkale and Anzele are important examples of the high water carrying capacity of basalts. These resources have been used for many years to meet the drinking and utility water needs of the settlements in the region.

5. Conclusion and Discussion

The water quality of the Karacadağ natural spring water basin was examined comprehensively with field studies, laboratory analyses and data evaluation processes carried out monthly between January 2020 and May 2021.

The analysis results of the water samples obtained from the Karacadağ basin on the determined parameters are presented in Table 3. These data were analyzed with statistical methods in order to evaluate the compliance of the waters with water quality standards.

Table 3. Karacadağ analysis results of wells in Karacadağ drinking water basins

Months/Parameters	January	April	July	September	November	January	April	May
Heat (T ° C)	19.70	25.60	28.8	26.65	23.40	21.08	22.90	25.20
PH (-log H)	8.23	8.10	7.96	8.34	7.79	7.82	7.90	7.96
EC (mmhos/cm)	212	218	203.6	256	238	267	241	224
Blur (Turb)	1,41	1.32	1.35	1.44	1.15	0.92	1.08	1.50
Color (PtCo)	6	5	6	6	5	5	4	4

NH ₃ -N(mg/l)	0,015	0.022	0.042	0.072	0.068	0.041	0.052	0.052
NO ₂ -N (mg/l)	0,003	0.005	0.007	0.004	0.004	0.006	0.008	0.002
NO ₃ -N(mg/l)	2.65	2.41	2.58	2.87	2.12	1.98	2.30	1.88
Cl(mg/l)	10.17	10,87	1.385	15.90	8.05	9.73	12.05	11.43
HCO ₃ (mg/l)	112	109.5	87.5	149.70	118	105.94	121.93	106.4
SO ₄ (mg/l)	0.875	0.025	2.85	6.50	1	4.25	3.60	1.15
Na (mg/l)	3.14	2.72	2.96	1.56	2.42	2.66	2.78	2.91
K (mg/l)	1.85	2.16	0,56	0,45	0,32	0,41	1.04	0,38
Ca (mg/l)	15.76	18.90	21.4	22.76	24.60	26.03	27.90	24.65
Mg (mg/l)	13.10	11.80	9.27	14.45	16,15	12,87	9.45	10.43

Within the scope of the study, variance analysis was performed to determine the change in parameter values in water samples taken in different months over time. The findings obtained showed that there were statistically significant differences between the months in the examined parameters. The variance analysis results revealed that the factors affecting water quality changed depending on seasonal changes.

Table 4. Regression analysis of the parameters examined in Karacadağ natural spring water

Parameters	Karacadağ natural spring water		
	Specification Coefficient	Coefficient of Uncertainty	Linearity Test
PH-EC	43,7	56,3	F=0,66 P>0.05 n.s
Na-K	36,2	63,8	F=0,74 P>0.05 n.s
Ca-Mg	3,5	96,5	F= 1,13 P>0.05 n.s

P>0.05n.s: It is appropriate to take it linearly.

P<0.05 *: It is not appropriate to take it linearly.

Table 5. Multiple regression and correlation analyses of Karacadağ natural spring water

RX1Y=-0,444 t=-1,213 SD=6 P>0.05n.s	RX2Y=-0,132 t=-0,326 SD=6 P>0.05n.s	RX1X2=0,207 t=0,517 SD=6 P>0.05n.s	RYX1X2=-0,457 t=-1, H5SD=5 P>0.05n.s RYX2X1=-0,046 t=-0,103 SD=5 P>0.05n.s	RYX 1X2=0,446
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P>0.05n.s: There is no significant relationship.

P<0.05 *: There is a significant level of relationship.

P<0.01 **: There is a very important level of relationship.

P<0.001 ***: There is an advanced level of relationship.

In the study, it was determined that there was a significant correlation between pH and electrical conductivity (EC) values in natural spring waters.

The analysis results show that pH and EC values were affected by each other in 43.7% of the water samples. The relationship between pH and EC values in natural spring waters is considered an important indicator in determining the chemical properties and pollution level of water. The study found that there was a significant correlation between sodium and potassium ions in natural spring waters. The analysis results show that sodium and potassium ions were affected by each other in 36.2% of the water samples. The tendency of sodium and potassium ions to move together in natural spring waters provides important information about the geochemical properties of the water.

The study found that there was a significant correlation between calcium and magnesium ions in natural spring waters.

The analysis results show that calcium and magnesium ions were affected by each other in 3.5% of the water samples. In the analysis results for NH₃-N, NO₂-N and NO₃-N, the following findings were obtained. In the analyses conducted on the natural spring waters of Karacadağ, no statistically significant correlation was found between the NH₃-N and NO₂-N parameters. There is no correlation between the measured values of NH₃-N and NO₃-N in the natural spring waters of Karacadağ. There is no correlation between the measured values of NO₂-N and NO₃-N in the natural spring waters of Karacadağ.

In the study, the anion-cation compositions (Table 2), bacteriological, inorganic and organic pollution loads (Table 3) and physical, chemical and microbiological properties (Table 3) of water samples taken from Karacadağ natural spring waters were analyzed in detail and the results were presented in tables.

Table 6. Karacadağ Wells anion-cation annual average values

Sampling data: 2020-2021					
İons	Mg/l	meq/l	% meq/l	T (°C)	21,233
Na ⁺	2,680	0,110	4,62	PH (-logH)	7,874
K ⁺	0,603	0,067	2,23	EC (mmhos/cm)	232,09
Ca ²⁺	44,29	1,18	51,36	Water Hardness (Fr)	10,765
Mg ²⁺	11,683	0,958	41,95	SAR (Sodyum Ad. Avarage) (%)	0,71
Cl ⁻	11,024	0,322	12,19	F _o (Foaming coefficient)	10,32
HCO ₃ ⁻	111,04	2,200	82,87	% Na	6,81
SO ₄ ⁻	5,843	0,142	4,39		
Total amount of cations (meq/l)				2,354	
Total amount of anions (meq/l)				2,687	
Total amount of ions (meq/l)				5,041	

The physical, chemical and microbiological properties of samples taken regularly from Karacadağ natural spring water for a period of eight months were evaluated by comparing them with international and national drinking water quality standards. The

obtained data provide a detailed examination in terms of the suitability of the water as drinking water and potential health risks.

Within the scope of the study, the parameter values specified in different international and national drinking water quality standards were compared with the analysis results. The differences observed between the standards in parameters such as pH and nitrate emphasize the importance of standard selection in water quality assessments. Therefore, it is necessary to make separate assessments for each standard to obtain more accurate results.

The anion-cation compositions of the water samples in the Karacadağ basin were hydrochemically classified using the Piper diagram (Figure 3). In this way, information was obtained about the origin and chemical properties of the waters at different points in the basin.

The piper diagram assessment revealed that all of the Karacadağ natural spring waters are located in the 5th Region (calcium-bicarbonate waters). This finding suggests that the geochemical evolution of the waters occurred under similar conditions and probably have the same origin.

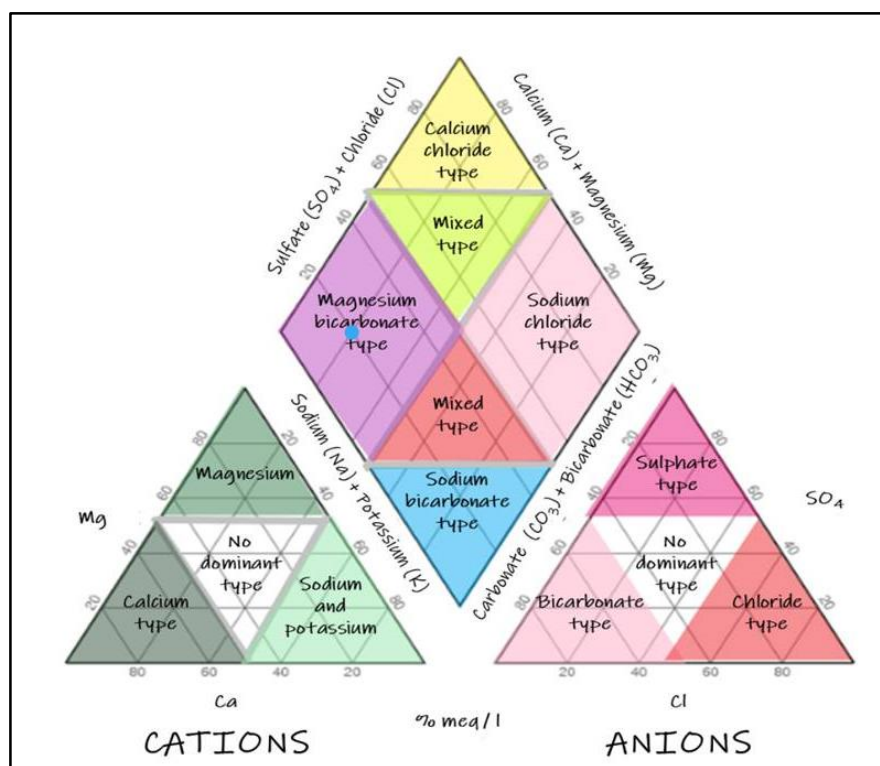


Figure 3. Diyarbakir Karacadağ natural spring water piper diagram

Schoeller diagram is a widely used tool in hydrochemical characterization of water samples. The diagrams obtained in the study emphasize that water samples are mostly in [water type] class and emphasize the importance of water-rock interactions.

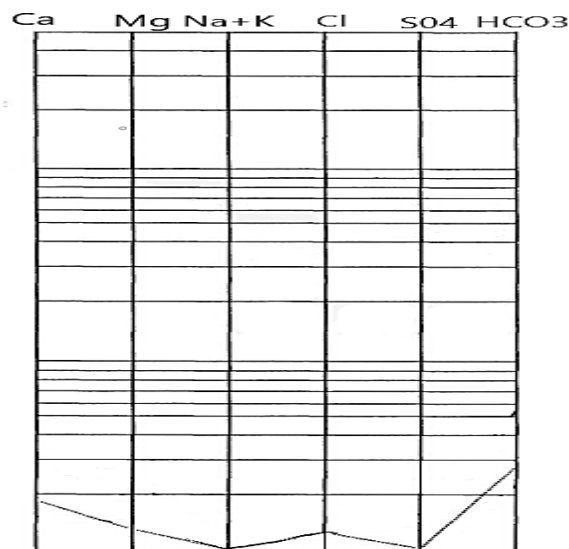


Figure 4. Diyarbakir Karacadağ natural spring water schoeller diagram

Hydrochemical analyses showed that basalt waters have a typical chemical composition. This composition is characterized by high concentrations of bicarbonate anion as well as Ca^{2+} , Mg^{2+} and Na^+ cations. Data obtained from drinking water sources support these findings.

While the amounts of cations in water samples are in a decreasing order as $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$, the order of $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$ is observed among anions. These results show that the chemical composition of waters is mostly calcium and magnesium bicarbonate character.

Hydrochemical analyses showed that calcium ion is more dominant than other cations in the studied water samples. This finding is consistent with the high calcium content reported for basalt waters in the literature and emphasizes the importance of water-rock interactions.

The hydrochemical properties of water samples were evaluated within the framework of TSE, WHO and EC drinking water standards (Table 4). The graphs presented in Figures 7-21 show the compliance of the values of different parameters of the samples with the standard limits. This comparison provides important information about the quality of water resources.

Table 6 shows the TSE 266 Turkish Standards, European Union Standards (2018) and World Health Organization Standards (2022) that limit the parameters of drinking water.

Temperature varies according to the season. pH value; It is between the minimum and maximum values given for TSE, WHO, EC standards. Conductivity value; It is determined that it remains within the limits specified by TSE, WHO, EC standards. Turbidity values; It does not exceed the values given for TSE, WHO, EC standards. Color value; It does not exceed the values of TSE, WHO and EC standards. Magnesium value; It gives measurements within the range of recommended values of standards in all waters in the basin.

Table 6. TSE 266 Turkish Standards, Institution EC European Union and WHO World Health Organization drinking water standard values

STANDARDS	TSE 266 Turkish Standards	Institution EC European Union	WHO World Health Organization
Microbiological EMS/100 mL			
Coliform	0	0	0
Esherichia Coli (E.Coli)	0	0	0
Total Chloronia Count (22C')	20		
Total Chloronia Count (37C')	5		
C.perfringers	0	0	0
Pseudomonas Aeruginosa	0	0	0
Chemical mg/L			
pH	6,5-9,5	6,5-9,5	6,5-9,5
Conductivity 20' (uS/cm)	2500	2500	2500
Nitrate (NO ₃)	50	50	50
Nitrite (NO ₂)	0,50	0,50	0,50
Boron (B)	1,0	2,0	2,0
Nickel (Ni)	0,02	0,02	0,02
Arsenic (As)	0,01	0,01	0,01
Cadminium (Cd)	0,005	0,005	0,003
Mercury	0,001	0,001	0,001
Total Chromium (Cr)	0,05	0,05	0,05
Barium			
Fluoride (F)	1,50	1,50	1,50
Lead (Pb)	0,01	0,01	0,01
Cyanide (CN)	0,05	0,05	0,07
Bromate (Br)	0,010	0,010	0,025
Benzene (C ₆ H ₆)	0,001	0,001	0,010
Selenium (Se)	0,010	0,010	0,010
Antimony (Sb)	0,005	0,005	0,005
Copper (Cu)	2,0	2,0	2,0
Phosphorus	0,4-5,0	0,4-5,0	
Iron (Fe)	0,2	0,2	0,3
Zinc	5,0		
Manganese (Mn)	0,05	0,05	0,10
Magnesium (Mg)	50	50	
Aluminum (Al)	0,20	0,20	0,20
Ammonium (NH ₄)	0,50	0,50	1,50
Sodium (Na)	175	200	200
Potassium (K)	12		
Free Chlorine (Cl ₂)	0,5	0,5	5
Chloride (Cl)	250	250	250
Calcium (Ca)	200		100
Sulfate (SO ₄)	250	250	250
Hardness (CaCO ₃)			500
Physical and Sensory (Organoleptic)			
Color (Co-Pt unit)	20	20	15
Turbidity (NTU unit)	5,0	4,0	5,0
Smell	Sensory	Sensory	Sensory
Taste	Sensory	Sensory	Sensory

Ammonium (NH₄) values do not exceed the range of recommended values of TSE, WHO and EC standards. Nitrite and Nitrate values; It gives measurements within the

range of recommended values of standards. Sulfate values; It does not exceed the values given for TSE, WHO, EC standards. Calcium values; It gives measurements within the range of recommended values of standards in waters in all basins. Sodium values; It does not exceed the values of TSE, WHO and EC standards. Potassium values; It gives measurements within the range of recommended values of standards.

Total Coliform and fecal streptococcus values; It gives measurements well above the value ranges of TSE, WHO and EC standards. Irrigation water quality assessment of water samples was carried out based on sodium adsorption ratio (SAR) and electrical conductivity (EC) parameters. Salinity and Wilcox diagrams of the US Department of Agriculture are widely used tools for irrigation water classification of water samples. In this study, the obtained data were evaluated on these diagrams and it was determined whether the water samples could be used as irrigation water

The sodium hazard of water samples was analyzed with the US Salinity diagram. The values obtained by the sodium adsorption ratio (SAR) calculation were used to determine their positions on the diagram together with the electrical conductivity (EC) values. In this way, the classification of water samples in terms of the potential negative effects of sodium on soil structure was carried out.

Hydrochemical analyses have shown that Karacadağ natural spring waters fall into the C1S1 irrigation water class. This classification shows that the waters have low salinity and sodium content and therefore are a safe irrigation source for all types of plants.

The Wilcox diagram is a graphical tool used to assess the quality of irrigation waters, like the US Salinity Diagram. In this diagram, the sodium percentage is used instead of the sodium adsorption rate, allowing the classification of waters in terms of both salinity and sodium hazard. The sodium percentage, evaluated together with the electrical conductivity value, reveals the effects of water on the soil more clearly.

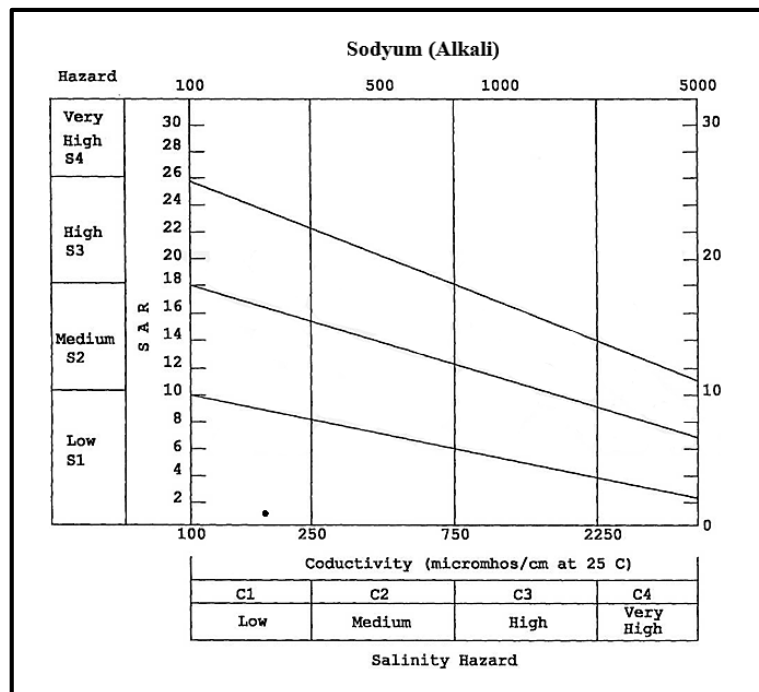


Figure 5. Diyarbakir Karacadağ natural spring water U.S.A. salinity diagram

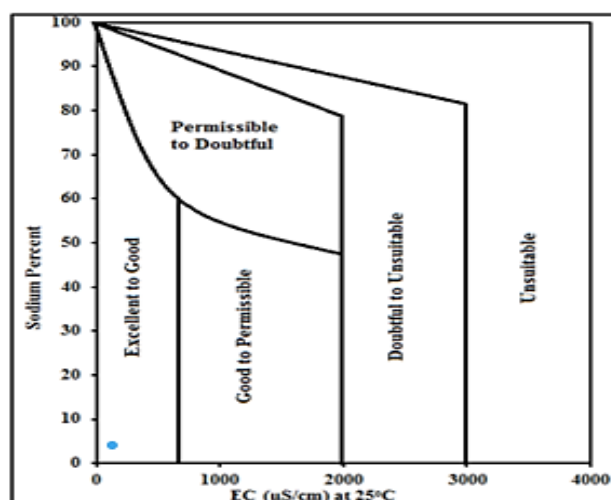


Figure 6. Diyarbakir Karacadağ natural spring water Wilcox diagram

When the data obtained as a result of hydrochemical analyses were evaluated on the Wilcox diagram, it was determined that Karacadağ natural spring waters were in the 'very good-good' irrigation water class. This finding shows that the waters have low salinity and sodium content and therefore have a low probability of creating negative effects on the soil structure.

Table 7. Eight-month analysis results of Karacadağ drinking water

Parametreler/Aylar	January	April	July	September	November	January	April	May
PH (-log H)	8,23	8,1	7,96	8,34	7,79	7,82	7,9	7,96
EC (mmhos/cm)	212	218	203,6	256	238	267	241	224
Turbidity	1,41	1,32	1,35	1,44	1,15	0,92	1,08	1,5
Color (PtCo)	6	5	6	6	5	5	4	4
NH ₄ (mg/l)	0,015	0,022	0,042	0,072	0,068	0,041	0,052	0,052
N ₀₂ -N (mg/l)	0,003	0,005	0,007	0,004	0,004	0,006	0,008	0,002
NO ₃ -N(mg/l)	2,65	2,41	2,58	2,87	2,12	1,98	2,3	1,88
Cl(mg/l)	10,17	10,87	13,85	15,9	8,05	9,73	12,05	11,43
SO ₄ (mg/l)	0,875	0,025	2,85	6,5	1	4,25	3,6	1,15
Na (mg/l)	3,14	2,72	2,96	1,56	2,42	2,66	2,78	2,91
K (mg/l)	1,85	2,16	0,56	0,45	0,32	0,41	1,04	0,38
Ca (mg/l)	15,76	18,9	21,4	22,76	24,6	26,03	27,9	24,65
Mg (mg/l)	13,1	11,8	9,27	14,45	16,15	12,87	9,45	10,43
Total Coliform	98	95	100	92	97	98	95	100
F.Stept (EMS/100 mi.)	20	20	23	25	22	26	26	20

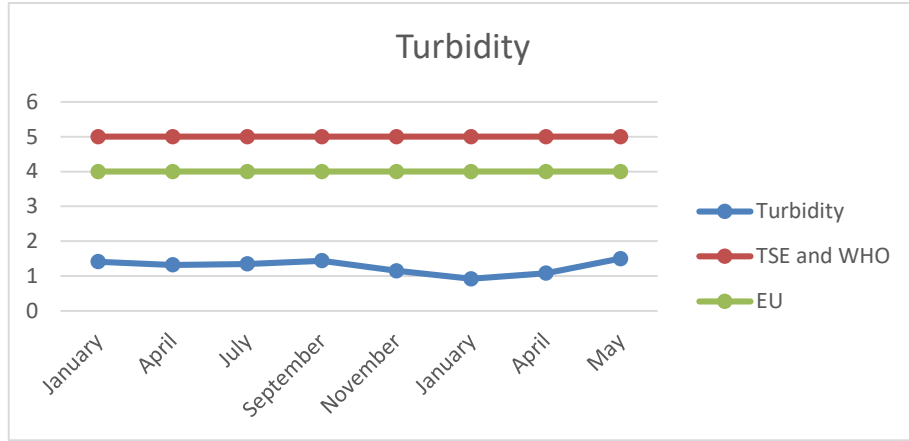


Figure 7. Comparison of Karacadağ natural spring water turbidity values with TSE, WHO and EC standards

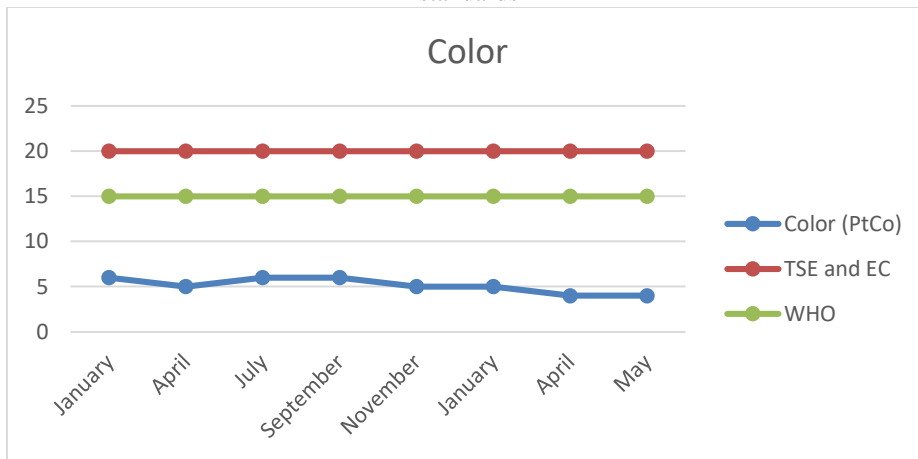


Figure 8. Comparison of Karacadağ natural spring water color values with TSE, WHO and EC standards

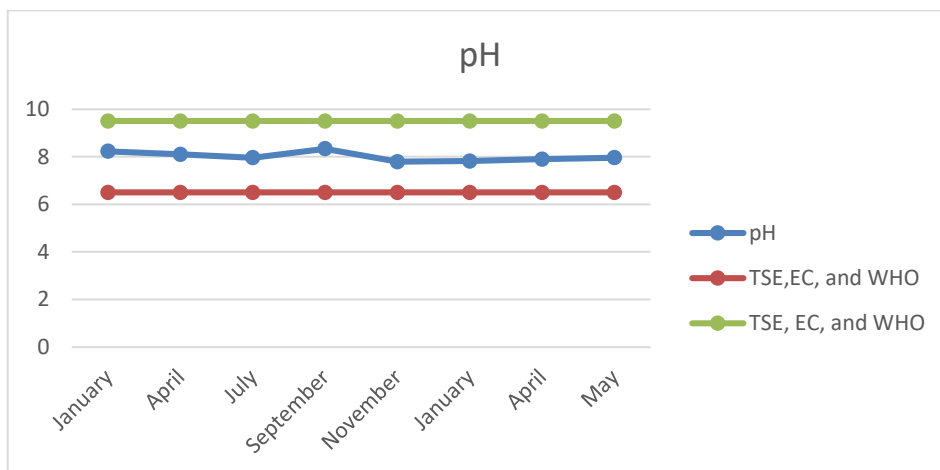


Figure 4. Comparison of Karacadağ natural spring water pH values with TSE, WHO and EC standards

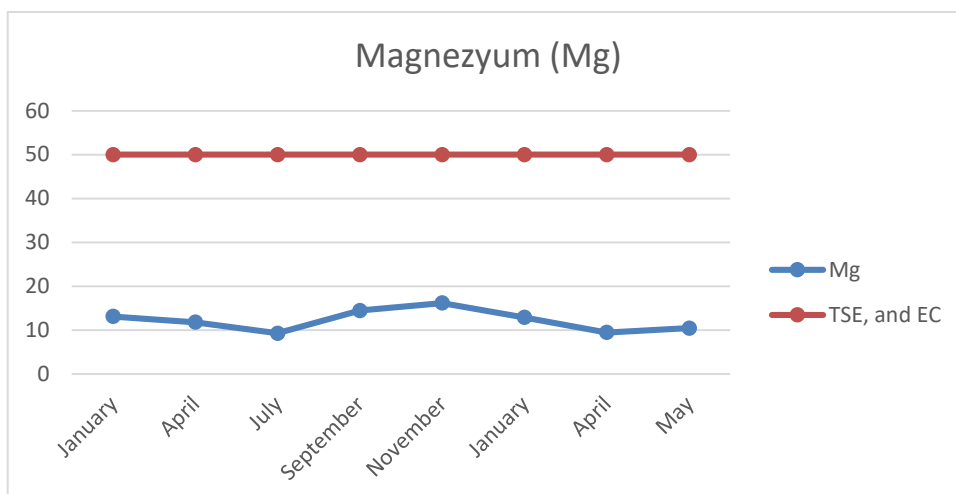


Figure 5. Comparison of Karacadag natural spring water magnezyum values with TSE, WHO and EC standards

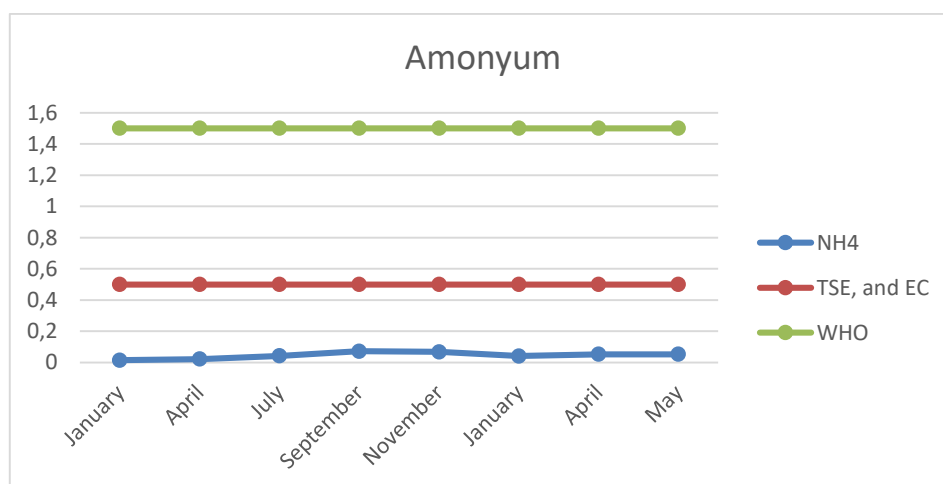


Figure 6. Comparison of Karacadag natural spring water amonyum values with TSE, WHO and EC standards

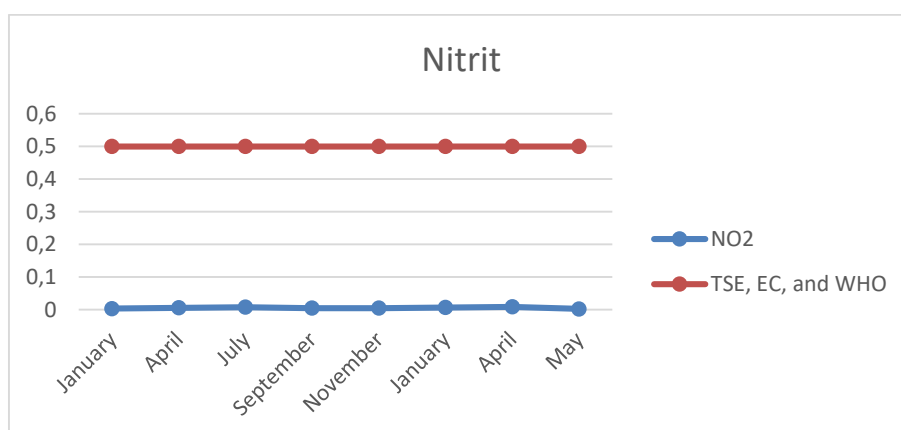


Figure 7. Comparison of Karacadağ natural spring water nitrit values with TSE, WHO and EC standards

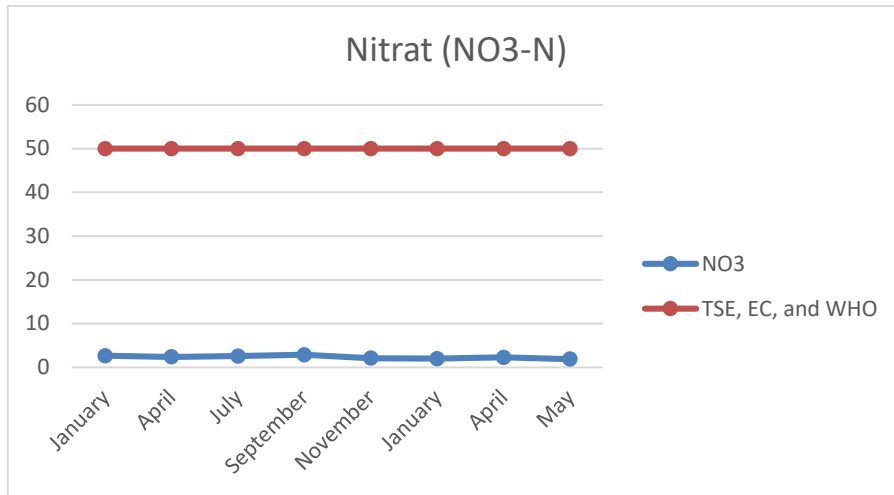


Figure 8. Comparison of Karacadağ natural spring water nitrat values with TSE, WHO and EC standards

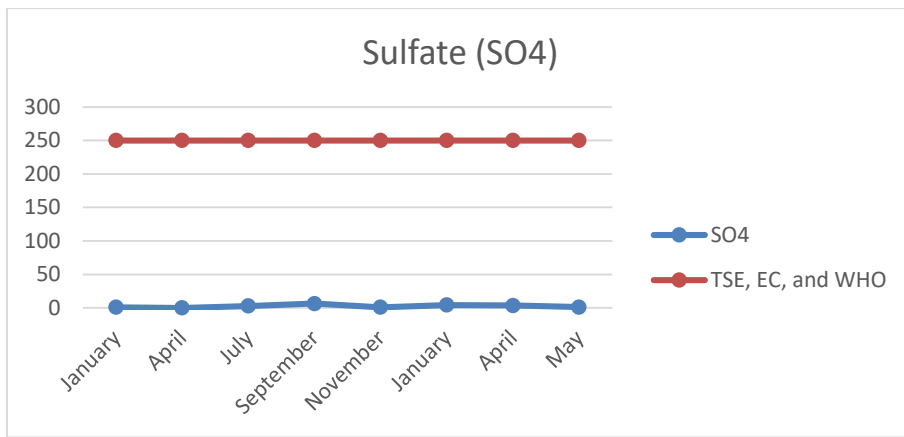


Figure 9. Comparison of Karacadağ natural spring water sulfate values with TSE, WHO and EC standards

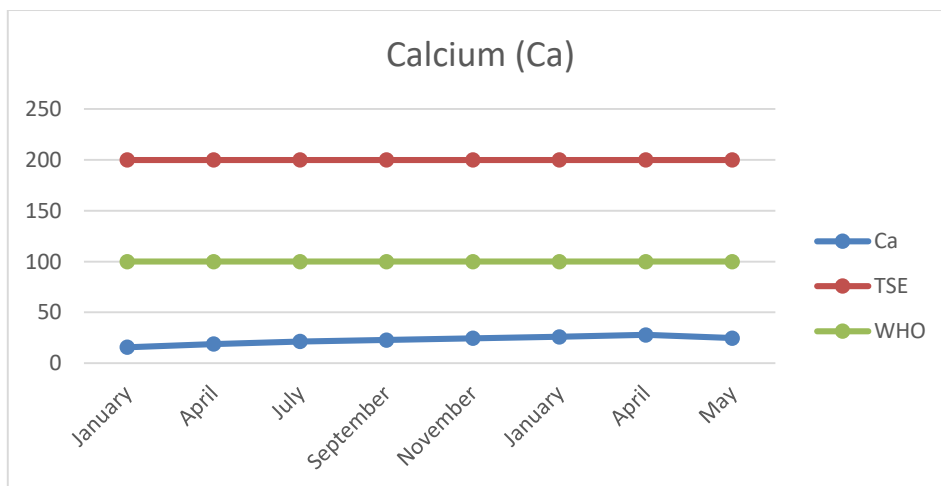


Figure 10. Comparison of Karacadağ natural spring water calcium values with TSE, WHO and EC standards

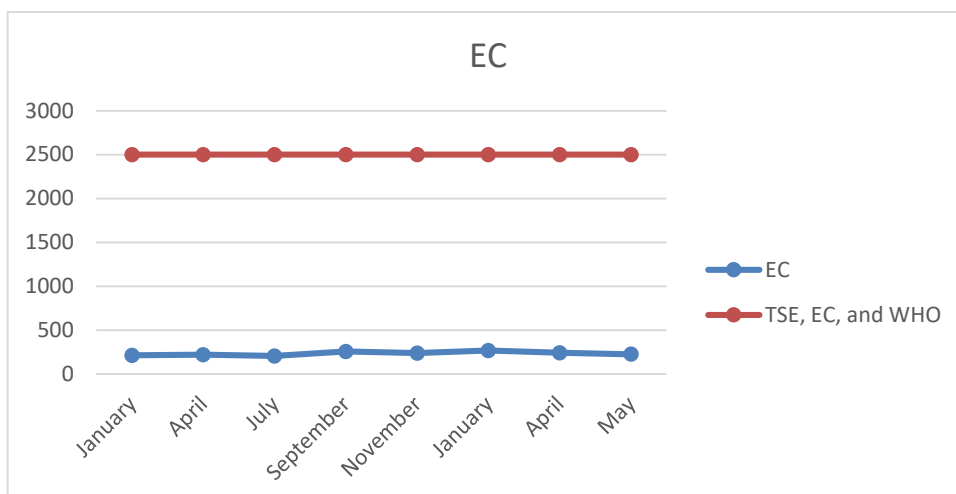


Figure 11. Comparison of Karacadağ natural spring water electrical conductivity values with TSE, WHO and EC standards

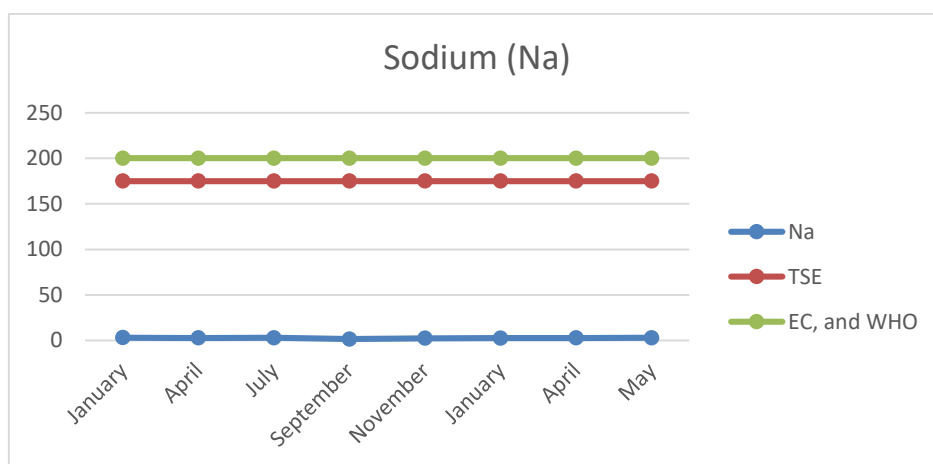


Figure 12. Comparison of Karacadağ natural spring water sodium values with TSE, WHO and EC standards

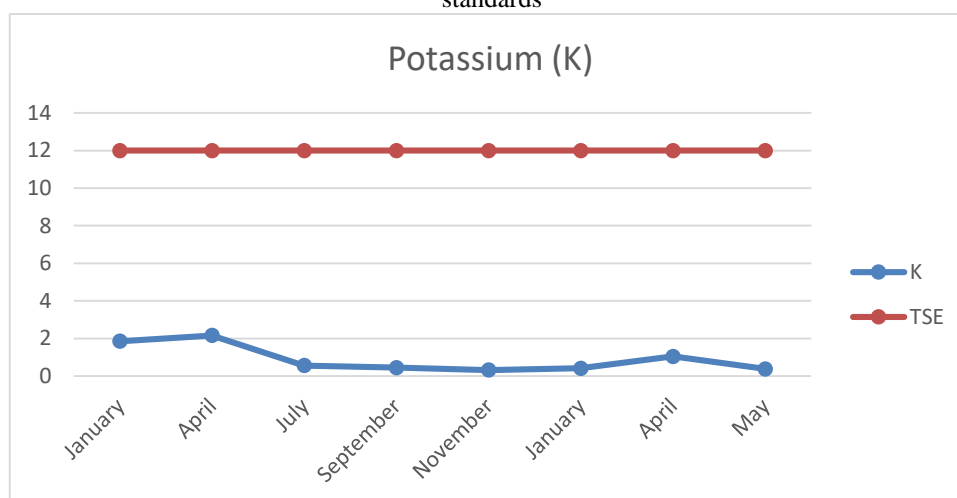


Figure 13. Comparison of Karacadağ natural spring water potassium values with TSE, WHO and EC standards

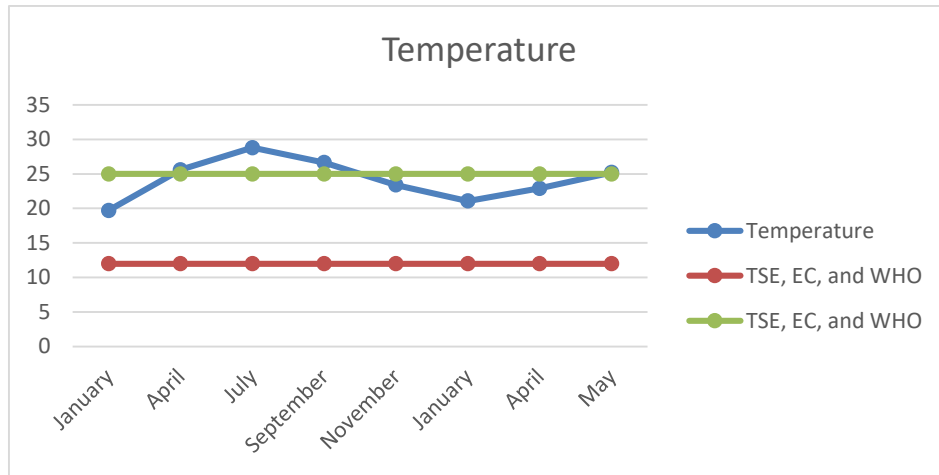


Figure 14. Comparison of Karacadağ natural spring water temperature values with TSE, WHO and EC standards

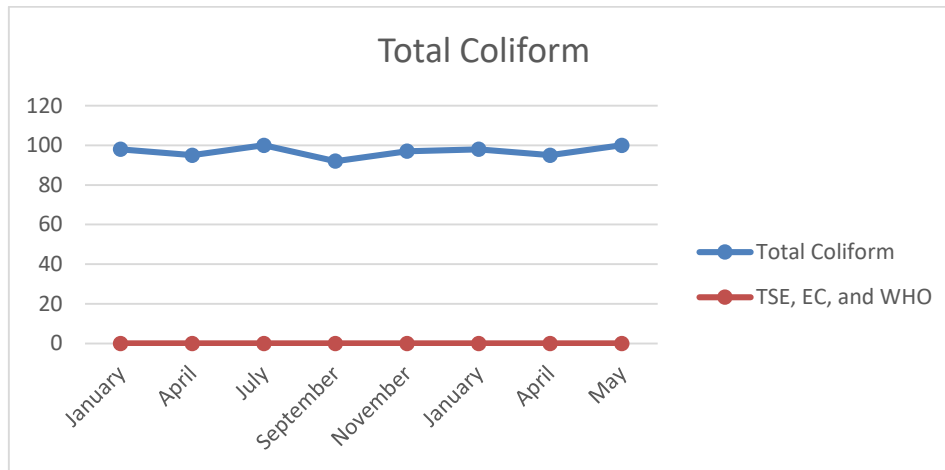


Figure 15. Comparison of Karacadağ natural spring water total coliform values with TSE, WHO and EC standards

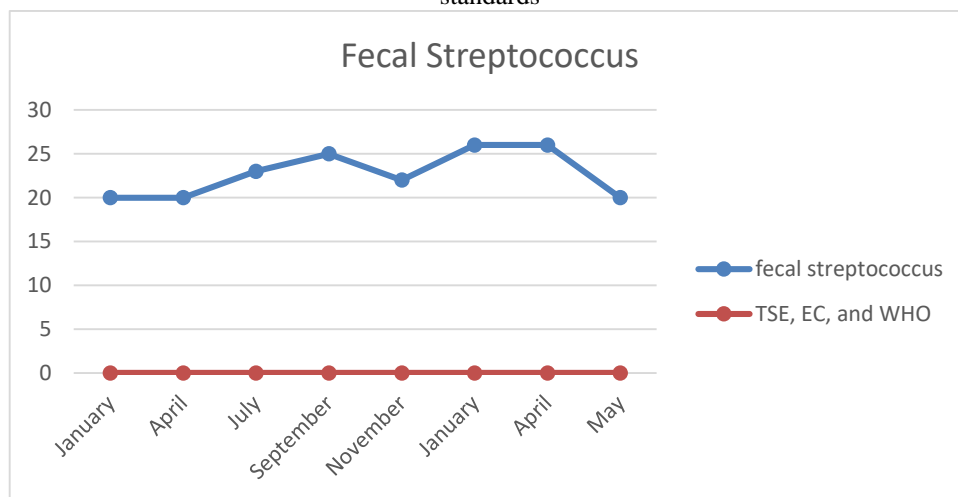


Figure 16. Comparison of Karacadağ natural spring water fecal streptococcus values with TSE, WHO and EC standards

A comparative examination of graphical data with international norms shows that the parameters specified in the table exceed the standard criteria for samples collected from the study area.

Table 8. Parameters exceeding the limits in international standards

Parameters	Months							
	January	April	July	September	November	January	April	May
Total Coliform	98	95	100	92	97	98	95	100
F. Stept (EMS/100 mi.)	20	20	23	25	22	26	26	20

Drinking water is of critical importance for human health and should not contain pathogenic microorganisms. Inadequate infrastructure causes chemicals and waste substances to mix directly into water resources.

Water pollution is a potential source of many diseases with the presence of various microorganisms.

Dissolved inorganic substances, bacteria, parasites and viruses cause waterborne diseases.

The symptoms of waterborne infections vary depending on the causative microorganism. Contaminated water causes diarrhea, dysentery, typhoid, hepatitis and other infectious diseases. Waterborne pathogens cause various infections that threaten human health. Inadequate infrastructure paves the way for the contamination of water resources and thus increases public health risks. Water pollution leads to the spread of various pathogens and the emergence of many diseases in humans. The clinical symptoms of waterborne diseases differ depending on the type of causative microorganism (Ibadullayeva *et al.*, 2019).

6. Results

As a result of the Piper diagram evaluation, all of the examined water samples were clustered in the 5th region. This situation shows that the carbonate hardness of the waters is higher than the non-carbonate hardness and therefore the calcium carbonate and magnesium carbonate contents are dominant. This finding shows that the waters have the carbonate hardness characteristic.

The use of Karacadağ natural spring waters as drinking water carries a risk due to excessive increases in some water quality parameters. The analyses conducted show that the limit values determined by Turkish Standards, World Health Organization and European Union standards are exceeded in parameters such as fecal *streptococcus* and coliform bacteria. In particular, the values measured in microbiological parameters such as fecal streptococcus and total coliform are well above the maximum acceptable levels. This situation shows that the water is at risk of fecal contamination and therefore poses a serious threat to drinking water safety. In the literature, it is reported that total coliform (*T. Coli*), fecal *streptococci* (F. Strept) and some other parameters increase in groundwater after rainfall events (Yetiş, 2015). Similarly, significant increases were observed in total coliform (*T. Coli*), fecal *streptococci* (F. Strept) and some other parameters in the natural spring waters in our research area during the rainy season. This suggests that the pollution is caused by a combination of factors such as inadequate infrastructure around the basin, agricultural activities, waste from industrial facilities and

geological features of the ground. This pollution poses serious risks to human health. The symptoms of waterborne infections vary depending on the causative microorganism. Contaminated water causes diarrhea, dysentery, typhoid, hepatitis and other infectious diseases. Waterborne pathogens cause various infections that threaten human health (Ibadullayeva *et al.*, 2019).

Factors such as location selection, depth and filter system of wells to be opened in basins should be determined meticulously and the surroundings of the wells should be isolated with appropriate barriers. Regular disinfection of wells designed to provide water supply from deep sections of the aquifer is of great importance in terms of preventing microbiological contamination and thus reducing risks to public health.

The natural spring waters examined are in the carbonated water class, where carbonate and bicarbonate ions are dominant. In terms of chloride and sulfate ions, they are evaluated in the category of ordinary chloride and ordinary sulfate waters, respectively. The calculations made showed that the waters are below sulfate saturation. In other words, the value of $[(rSO_4)/(rCa^{++})]$ 0.5, which expresses the relationship between sulfate and calcium ions, remains below 70 meq/L and the sulfate ion (SO_4) concentration is lower than the calcium ion (Ca^{++}) concentration.

The high Ca^{2+} , Mg^{2+} and HCO_3^- contents of the waters are the result of the interaction of the basins with carbonate and basaltic rocks. This situation is compatible with the general geological structure of the basins.

When the Wilcox diagram is evaluated, irrigation waters in all basins are in the “very good” and “good” classes. According to the US salinity diagram, these waters are classified as “low salt” and “low sodium”. This situation shows that the waters in question can be used in all types of soil and plants without any risk of salinity or sodium.

The pollution level in natural spring waters is determined by the combination of multiple factors such as the depth of the spring water, the presence and thickness of the protective layer, the distance and type of pollutant sources, the water permeability of the aquifer, the geological structure and topographic features of the basin. The interaction of these factors creates a complex system that directly affects the quality of groundwater.

A comprehensive infrastructure system needs to be established to prevent wastes originating from settlements, industrial facilities and agricultural activities, which are among the main causes of pollution of natural spring waters, from reaching groundwater. In addition, in the regions determined for the protection of natural spring water recharge basins, scientific research should be conducted by taking into account factors such as the soil characteristics, geological structure and socio-economic conditions of the basin and the protection-use balance should be observed.

Effective water quality assessment is essential for preserving aquatic ecosystem health. With increasing water pollution, rigorous evaluation is necessary to protect human well-being. Geospatial technology, especially GIS, enables large-scale water quality monitoring. This article examined the integration of geospatial and in situ data to improve understanding of aquatic water quality dynamics. Satellite remote sensing provides extensive data on water optical and thermal properties, while in situ observations offer critical ground truth. The role of machine learning and AI in analyzing complex datasets for enhanced modeling and parameter retrieval is explored. Challenges like resolution limitations and data integration are addressed, along with solutions such as data assimilation and real-time monitoring. This chapter aims to provide researchers and managers with practical guidance for developing accurate water quality models using integrated geospatial and in situ approaches (Kumari *et al.*, 2023).

In combating declining groundwater levels, the implementation of artificial recharge systems emerges as a critical strategy for balancing the water cycle and replenishing groundwater reserves.

For the sustainability of groundwater resources, the integration of artificial recharge techniques is essential for the restoration of hydrological systems and the long-term management of water resources.

The establishment of protected areas around water resources is a fundamental approach to minimizing pollution risks and preserving water quality.

For the protection of water resources, the identification of sensitive areas and the implementation of stringent protection measures in these areas are vital for ecosystem health and human well-being.

To reduce chemical input usage and improve soil health, the promotion of sustainable agricultural practices is necessary for the protection of water resources and the long-term sustainability of agricultural production. The adoption of sustainable agricultural techniques contributes significantly to the sustainable management of water resources by optimizing water usage, preventing soil erosion and preserving biodiversity.

The management of water resources requires a multidisciplinary approach, involving collaboration among various fields such as hydrology, geology, ecology, agriculture and socio-economics. The monitoring and implementation of technological innovations are necessary for the protection and efficient utilization of water resources.

For the sustainable management of water resources, the participation and awareness of local communities, as well as the adoption of transparency and accountability principles in decision-making processes, are of great importance.

Numerous studies highlight the value of multi-criteria decision-making (MCDM) methods, such as AHP, ANP, TOPSIS, VIKOR, PROMETHEE, ELECTRE, Fuzzy set theory, GRA and SAW, in groundwater quality assessment. These methods structure decision-making in complex environments, allowing for multi-criteria evaluation and alternative comparison. The coupling of MCDM with Geographic Information Systems (GIS) enables the creation of groundwater quality maps and spatial contamination risk assessments. Future research should focus on innovative data collection, improved modeling and artificial intelligence applications to enhance groundwater quality evaluations. This will lead to more accurate and reliable decisions for groundwater resource management.

Training programs and workshops can be organized to increase the knowledge level of the local population regarding the use and protection of water resources. Advisory boards or platforms can be created to ensure the active participation of the local population in water management processes. Research can be conducted to evaluate the traditional water management practices and knowledge of the local population and integrate them with modern methods.

In order to develop effective water resource management strategies for the Karacadağ basin, a detailed review of global exemplars, focusing on drought resilience, pollution abatement and distribution efficiency, will be conducted to identify applicable management structures, technological implementations and funding approaches and to glean actionable insights from the critical analysis of their outcomes.

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