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A Multi-Dimensional Hydrogeochemical Assessment and Water Quality Analysis of Groundwater Resources in Yozgat Province

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Groundwater, Hydrogeochemistry, Water quality, Yozgat Province, Piper Diagram, Multivariate analysis.

Abstract: In this study, it was aimed to evaluate the hydrogeochemical properties and water quality for drinking, agricultural irrigation and other purposes of ground water resources within the boundaries of Yozgat Province. Within the scope of the study, the analysis results of water samples taken from 79 wells in 12 districts within the provincial borders between 2016 and 2019 were examined. Hydrogeochemical evaluation of water samples was performed according to Piper diagram, Spearman correlation, Gibbs diagram, Cluster analysis and Factor analysis. Water quality was evaluated according to standards and regulations regarding drinking water, utility and agricultural irrigation. According to the results of Spearman correlation analysis, the highest relationships were observed between electrical conductivity (EC), sulfate (SO_4) and total dissolved solids (TDS). There are two different types of groundwater in the region: water with Ca-Mg-Cl and water with Ca-Mg-HCO_3, and it has been concluded that the rock dominant mechanism is effective on the quality of water resources. Cluster analysis showed that regions close to each other have similar water characteristics due to similar geological structure. In factor analysis, Factor 1 constitutes 41% of the total variance. Additionally, it has been determined that the water resources in the region are suitable for drinking use and agricultural irrigation.

Yozgat İli Yeraltı Suyu Kaynaklarının Çok Boyutlu Hidrojeokimyasal Değerlendirmesi ve Su Kalitesi Analizi

Anahtar Kelimeler

Yeraltı suyu, Hidrojeokimya, Su kalitesi, Yozgat İli, Piper Diyagramı, Çok Değişkenli Analiz.

Özet: Bu çalışmada Yozgat İli sınırları içerisinde yer alan içme, tarımsal sulama ve diğer amaçlı yeraltı su kaynaklarının hidrojeokimyasal özellikleri ve su kalitesinin değerlendirilmesi amaçlanmıştır. Çalışma kapsamında 2016-2019 yılları arasında il sınırları içerisinde yer alan 12 ilçedeki 79 kuyudan alınan su numunelerinin analiz sonuçları incelendi. Su örneklerinin hidrojeokimyasal değerlendirmesi Piper diyagramı, Spearman korelasyonu, Gibbs diyagramı, Cluster analizi ve Faktör analizine göre yapılmıştır. Su kalitesi içme suyu, kullanım ve tarımsal sulama ile ilgili standart ve yönetmeliklere göre değerlendirildi. Spearman korelasyon analizi sonuçlarına göre en yüksek ilişkiler elektriksel iletkenlik (EC), sülfat (SO_4) ve toplam çözünmüş katılar (TDS) arasında gözlendi. Bölgede Ca-Mg-Cl'li su ve Ca-Mg-HCO_3'lü su olmak üzere iki farklı yeraltı suyu mevcut olup, kaya baskın mekanizmasının su kaynaklarının kalitesi üzerinde etkili olduğu sonucuna varılmıştır. Kümeleme analizi birbirine yakın bölgelerin benzer jeolojik yapı nedeniyle benzer su özelliklerine sahip olduğunu göstermiştir. Faktör analizinde, Faktör 1 toplam varyansın %41'ini oluşturmaktadır. Ayrıca bölgedeki su kaynaklarının kullanıma ve tarımsal sulamaya uygun olduğu tespit edilmiştir.

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1. Introduction

Water is a fundamental element for the existence and thriving of humans and other living beings [1]. With industrialization, agriculture, and population growth, the demand for freshwater resources is increasing day by day. Additionally, climate change alters the natural environment, making the protection of our water resources more challenging. Although surface waters such as lakes and rivers are the main readily available freshwater sources, their availability is relatively limited on a global scale. Thus, the reliance on groundwater to supply water needs has been increasing in recent times [2]. Groundwater with high water quality is an important and reliable source and can primarily be used as a source of drinking water [3]. In addition, groundwater plays a vital role in various sectors, including agriculture, livestock, industry, and mining [4,5]. In recent years, characterizing the hydrogeochemical characteristics of groundwater is becoming more important, particularly as more and more places rely on it for drinking and irrigation. In order to use groundwater resources more effectively, their hydrogeochemical properties need to be well understood, and they need to be continuously monitored and evaluated [6,7].

The literature highlights the significance of hydrogeochemical research in developing sustainable groundwater management strategies to tackle issues related to water supply and quality in different parts of the world. A study by Nagarajan et al. [8] examined 102 groundwater samples from Thanjavur, India, with particular attention to main ions, pH, electrical conductivity (EC), temperature, and nitrates. According to their findings, Na and Cl ions predominated in 90% of the samples, and a sizable percentage of the water types were Ca-Mg-Cl type waters. The study demonstrated the negative effects of human activity on groundwater quality, highlighting how urgent it is to implement practical conservation measures. Similarly, the hydrogeochemical characteristics of the surface and groundwater of the Aksu (Isparta) Plain were assessed by Şener and Güneş [9]. The waters were mostly in the Ca-HCO_3, Mg-HCO_3, and Ca-Mg-HCO_3 water facies, according to the analytical results based on the Piper diagram. In the same manner, Piper, Schoeller, Wilcox, and US Salinity Laboratory diagrams were used to assess hydrogeological formations in the study of Küçükatabey [10] in Gemici Village (Baskil). The predominant anion was found to be HCO_3, and the predominant cation was found to be Ca in the water from 11 wells and 3 springs.
In the Middle Ganga Basin of India, research by Patel et al. [7] research on the shallow aquifer system, revealing that the groundwater is slightly alkaline with a cation dominance order of Na > Ca > Mg > K and an anion dominance of bicarbonate (HCO_3). Their findings highlight the critical reliance on groundwater in the region for both irrigation and drinking purposes, alongside observed reductions in water quantity and quality. Ren et al. [11] utilized multivariate statistical techniques, including Principal Component Analysis (PCA) and Factor Analysis (FA), to dissect the hydrogeochemical dynamics within the central Guanzhong Basin, pinpointing mineral dissolution/precipitation and human influence as primary determinants of groundwater quality. Barzegar et al. [12] focused on identifying the main factors deteriorating groundwater quality in the Hoy Plain, northwest Iran, using the PHREEQC model and Piper diagram. Their findings indicated that the majority of samples from free aquifers and all samples from confined aquifers fell within the Ca-Mg-HCO_3 type, suggesting various processes and factors could influence water quality in the region. Ates et al. [3] evaluated 28 physicochemical variables for groundwater in the stratovolcano aquifers of Mount Erciyes over a period of 12 months at 13 sampling stations. All water samples exhibited roughly similar characteristics, with some variations in ion concentrations. All water samples were of the Ca-Mg-HCO_3 type, with Ca and Mg as the dominant cations and HCO_3 as the dominant anion. The saturation index results indicated that the water samples were almost saturated with carbonate minerals but undersaturated with SO_4 minerals. In the study of Bozdağ [13] on the Konya Plain, hydrogeochemical properties and suitability for irrigation of groundwater was analyzed, using seven parameters and Wilcox and US Salinity Laboratory diagrams. The study revealed dominant Ca and Mg cations and an anion facies progression from HCO_3 to SO_4-Cl. It found that the Late Pliocene-Quaternary aquifer, especially near Üçhüyükler, Ovakavağı, and Karkın, was adversely affected by agricultural and anthropogenic activities, making it unsuitable for irrigation purposes.

Furthermore, studies by Ghoraba and Khan [14] in Pakistan, Ke et al. [15] in the Qinghai-Tibet Plateau's permafrost regions of China, Kortatsi et al. [16] in Ghana's Offin Basin, Mukherjee and Singh [17] in five main river basins of India, Abdelshafy et al. [18] in Sohag, Egypt, Li et al. [19] in northwest China, Malik et al. [20] in Rajasthan, India, Krishna Kumar et al. [21] in Tamil Nadu, India, and Wu et al. [22] in the Hangjinqi gas field area, Northwest China, further contribute to our understanding of groundwater's hydrogeochemical characteristics. These studies collectively highlight the complex interplay of geological and anthropogenic factors in shaping groundwater quality across diverse ecological and climatic zones.

The objective of this research is to assess the quality of Yozgat Province's groundwater and identify its hydrogeochemical characteristics by analyzing groundwater sample material. This study examined the water quality of 79 wells located in 12 districts between 2016 and 2019 using data of the DSI 12th Regional Directorate about irrigation water sources. Water sample analysis was performed using hydrogeochemistry. Water quality was evaluated according to standards and regulations regarding drinking water, utility, and agricultural irrigation. The novelty of this study lies in its comprehensive hydrogeochemical assessment of groundwater resources across Yozgat Province, using a robust dataset of water samples collected from 79 wells over a three-year period (2016-2019). Key findings include the identification of two distinct groundwater types linked to geological characteristics, and insights into how regional geological similarities influence water quality. The study also demonstrates that a significant portion of the variance in water characteristics is explained by factor analysis, underscoring its importance in understanding regional water resources. Overall, the research confirms the suitability of the region's water for its intended uses, grounding its conclusions in comprehensive data and advanced analytical methods.

2. Description of the Study Area

This study covers Yozgat Province and its surroundings, located on the Bozok Plateau of the central Kızılırmak in the Central Anatolia Region. It is surrounded by Orum, Amasya, Tokat in the north, Sivas in the east, Kayseri and Nevşehir in the south, and Kırşehir and Kırıkkale in the west [23]. Yozgat Province is 1,300 meters above sea level and has a land area of 1,407,200 hectares. It is located between 34°'05'–36°10' eastern meridians and 38°40'–40°18' northern parallels. The distance between the eastern and western ends of the province is 216 kilometers as the crow flies, and the distance between the northern and southern ends is 144 kilometers [23]. The location map of the research area is given in Figure 1.

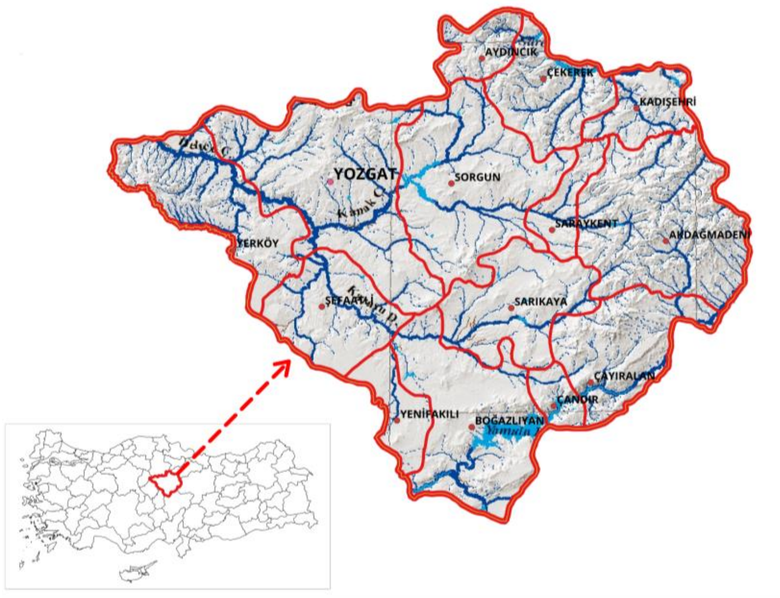

Figure 1. Map of Yozgat Province showing districts and rivers

Çekerek River, which drains the waters of the northern part of Yozgat, is one of the important tributaries of Yeşilırmak. It originates from the Çamlıbel Mountains within the borders of Sivas Province, flows from the south of the Deveci Mountains to the west and enters the borders of Yozgat Province. Delice River, one of the major branches of Kızılırmak, originates from the western foothills of the Akdağlar as a spring water, and reaches Şefaatli by taking the Sorgun stream, which collects the waters of Merkez, Sorgun and Doğankent. Here, it merges with the Karacaali Essence, which grows with the waters of Boğazlıyan and its surroundings and takes the name Delice River. There are no fish farms in the rivers of Yozgat region. However, trout farming is done on natural and artificial lakes formed by feeding streams. There is a 950 ton/year trout production facility on the Uzunlu Dam Pond, fed by the Delice River, a 450 ton/year trout production facility on the Gelingüllü Dam Pond, also fed by the Delice River, and a 200 ton/year trout production facility on the Yahyasaray Dam Pond, fed by the Çekerek River. There is no natural lake within the borders of Yozgat. However, 4.5 km away from Boğazlıyan district. There is a small lake in the source part of the Cavlak Thermal Spring located in the west, which the local people call "Cavlak Lake" [24].

3. Material and Methods

Hydrogeochemical studies can be examined in three stages: sampling, analysis, and evaluation. The results of the water quality analysis evaluated in this study were obtained from the DSI 12th Regional Directorate. The data covers analysis results taken from a total of 79 wells in 12 districts between 2016 and 2019 once in a year. Within the scope of the study, pH, EC, Na, K, Ca, Mg, CO_3, HCO_3, Cl, SO_4, % Na, SAR, hardness, NO_2, NO_3, NH_4, organic matter, and TDS parameters were evaluated. Water samples were collected from 13 wells in the Central district of Yozgat Province; 8 in Yerköy; 7 in Şefaatli; 9 in Sarıkaya; 7 in Sorgun; 9 in Çayıralan; 2 in Kadışehri; and 2 in Saraykent. A total of 79 wells were sampled, including 3 in Çandır, 1 in Çekerek, 8 in Akdağmadeni, and 12 in Boğazlıyan. The pH determination in groundwater was made using the TS EN ISO 10523 electrometric method. The EC value in water was determined using the TS 9748 EN 27888 method. Parameters analyzed included Na, % Na, K, Ca, Mg, NH_4, and SAR, within the scope of the TS EN ISO 14911 method. CO_3 and HCO_3 were analyzed using TS 3790 EN ISO 9963-1; Cl, SO_4, NO_2, and NO_3 were analyzed using TS EN ISO 10304-1; and organic matter according to TS 8195 EN 1484 methods. Standard methods were also used to analyze hardness and TDS parameters.

In this study, the annual average values and descriptive statistics (minimum, maximum, and standard deviation) values of the analysis results for 12 regions on a district basis according to the regional years between 2016 and 2019 were calculated with the help of the Excel program. Based on average values obtained from 2016 to 2019, the use of groundwater in the Yozgat region for drinking water purposes was evaluated according to TS 266-Water Intended for Human Consumption [25], the Regulation on Water Intended for Human Consumption [26], and the Regulation on the Protection of Groundwater Against Pollution and Deterioration [27]. Additionally, using the US Salinity Laboratory Diagram according to the Regulation on the Protection of Groundwater Against Pollution and Deterioration [28], its suitability for domestic and agricultural irrigation purposes was also assessed.

A normality test was performed with the analysis results of the samples taken from the region. Then, hydrogeochemical evaluations of groundwater were made using Spearman correlation, piper diagrams, clustering analysis, Gibbs diagrams, factor analysis, and anion cation relationships. Hypothesis tests can be used when evaluating normality [29]. In this study, a normality test was performed with the Shapiro-Wilk method using the Past program. The Spearman correlation is the non-parametric version of the Pearson correlation coefficient. It is used in non-normal data where parametric assumptions are not met. While there is a linear relationship in Pearson correlation, a non-linear relationship is mentioned in Spearman correlation [30]. In order to statistically evaluate the correlation relationship in groundwater analysis results, the Spearman correlation analysis method within the Excel program was used. Spearman correlation analysis was performed for a total of 17 parameters. Yozgat region groundwater analysis results were created by piper diagrams using the GW_Chart program. The GW_Chart program is a special graphics creation program used in groundwater research. Developed by the United States Geological Survey (USGS) [31]. In order to classify Yozgat Province groundwater quality data, Euclidean distance was used to calculate the differences between intermittent measurement levels in the past program. In the clustering analysis, the "Progressive Clustering (Hierarchical Cluster)" method was used. The Past program is a data analysis application developed by Oyvind Hammer for Windows [32]. In principal component analysis, the Scree test graph (line graph) shows the total variance related to each component. The components up to the point where the graph becomes horizontal are considered the maximum number of components to be obtained [33]. In the factor analysis conducted in this study, principal component analysis was applied using the Past program, and a Scree test graph was drawn.

To examine the anion-cation relationship in the region, graphs of anions and cations were created using Ca, Mg, Na, K, Cl, SO_4, and HCO_3 ions in groundwater using the Excel program. The chemical composition of water depends on many parameters, such as the chemical composition of the rock it is in contact with, the flow rate of groundwater, temperature, ambient pressure, ion activity, and ambient pH [34]. Ion activity is very important to determine the usability of groundwater and in which areas it can be used. For this reason, in order to examine the anion-cation relationship in the region, graphs of anions and cations were created using Ca, Mg, Na, K, Cl, SO_4, and HCO_3 ions in groundwater using the Excel program. Anion-cation relationships were evaluated in the graphs created.

4. Results

4.1. Hydrochemical characteristics of the water samples

In this study, hydrogeochemical evaluation was carried out in three stages. i) The groundwater quality data from the region were statistically analyzed for suitability as drinking water, in accordance with TS 266 Water Intended for Human Consumption [25] and the Regulation on Water Intended for Human Consumption [26]. ii) The suitability of groundwater for agricultural irrigation was evaluated using the US Salinity Laboratory Diagram and the Regulation on the Protection of Groundwater Against Pollution and Degradation. iii) Groundwater quality data were further analyzed through hydrogeochemical methods, including Spearman correlation, Piper diagram, cluster analysis, Gibbs diagram, and anion-cation relationship studies.

The average values of the water quality parameters between 2016 and 2019 were presented for 12 regions in Yozgat Province and given in Table 1. Besides, descriptive statistics were computed and shown in the table. pH values indicated almost neutral conditions, ranging from 7.49 to 7.88 in samples from 12 districts, with an average of 7.67. The conductivity of the samples varied from 539 to 1382 µS/cm, with an average of 774 µS/cm. The content of dissolved solids is linked to the conductivity of water samples. The total dissolved solids content (TDS) of the water samples is a parameter related to the conductivity and was determined to be 57–77% (average 69%) of the conductivity (Freeze and Cherry, 1979).

Table 1. The physicochemical characterizations of groundwater samples in Yozgat Province (2016-2019).

District	pH	EC	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	% Na	SAR[a]	T.H.[b]	NO_2	NO_3	NH_4	TOC[c]	TDS[d]
Unit	-	µS/cm	mg/L															
Merkez	7.65	682	45.8	1.6	78.0	22.2	0.1	391.6	8.6	43.6	22	1.55	284	0.14	32.6	0.18	0.61	465
Yerköy	7.75	1298	167.8	3.4	88.1	50.6	0.1	420.7	46.2	309.6	41	3.31	428	0.14	31.1	0.07	0.97	801
Şefaatli	7.70	1382	121.1	2.6	176.3	32.8	0.0	358.2	30.0	455.5	37	5.87	575	0.52	42.5	0.58	0.97	1065
Sarıkaya	7.81	637	46.3	1.2	77.3	12.1	1.3	312.4	16.9	34.3	27	2.29	242	0.2	42.7	0.08	0.82	433
Sorgun	7.59	695	30.2	2.0	91.4	24.3	0.0	396.6	5.1	45.6	14	0.77	328	0.14	31.4	0.09	0.84	475
Çayıralan	7.49	539	4.8	1.7	107.1	7.9	0.0	345.0	2.3	16.2	3	0.12	300	0.14	19.3	0.07	0.65	373
Boğazlıyan	7.63	906	53.8	5.3	106.1	30.5	0.0	351.0	39.8	108.6	18	1.02	393	0.22	93.1	0.07	0.95	665
Akdağmadeni	7.57	541	6.5	2.5	100.1	8.9	0.0	341.3	1.8	11.8	5	0.17	286	0.16	14.5	0.17	0.79	309
Saraykent	7.60	632	14.6	1.9	104.6	15.4	0.0	380.4	5.8	22.7	9	0.33	324	0.16	13.2	0.08	0.6	416
Kadışehri	7.71	842	36.4	8.6	79.6	45.1	0.0	406.8	14.4	86.3	13	0.73	384	0.2	53.2	0.08	0.56	628
Çekerek	7.73	568	14.6	2.1	65.4	33.3	0.0	359.7	4.1	24.1	10	0.37	300	0.14	5.5	0.06	0.61	371
Çandır	7.88	563	27.3	1.7	75.7	12.6	0.2	323.8	6.9	16.2	22	0.83	241	0.18	51.7	0.07	1.46	389
Min	**7.49**	**539**	**4.8**	**1.2**	**65.4**	**7.9**	**0.0**	**312.4**	**1.8**	**11.8**	**3**	**0.12**	**241**	**0.14**	**5.5**	**0.06**	**0.56**	**309**
Max	**7.88**	**1382**	**167.8**	**8.6**	**176.3**	**50.6**	**1.3**	**420.7**	**46.2**	**455.5**	**41**	**5.87**	**575**	**0.52**	**93.1**	**0.58**	**1.46**	**1065**
Average	**7.67**	**774**	**47.5**	**2.9**	**95.8**	**24.7**	**0.2**	**365.6**	**15.2**	**97.9**	**18**	**1.45**	**340**	**0.19**	**35.9**	**0.13**	**0.82**	**532**
Std.Dev.	**0.11**	**289**	**49.0**	**2.1**	**28.8**	**14.1**	**0.4**	**33.7**	**15.2**	**139.7**	**12**	**1.68**	**94**	**0.11**	**23.6**	**0.15**	**0.25**	**221**

[a]SAR: Sodium Adsorption Rate
[b]T.H: Total Hardness in mg $CaCO_3$/L
[c]TOC:Total Organic Carbon
[d]TDS: Total Dissolved Solids

The analysis results of the samples taken between 2016 and 2019 were evaluated according to TS 266) and the Regulation. According to the TS 266, water resources are classified into two classes (Class I Spring water, Class II Waters intended for human consumption other than spring water) and two types (For Class I, only single type and for Class II Type I Processed Spring water, Type II Drinking and process water). Considering the limit values of TS 266, the average EC values from 2016 to 2019 place Sarıkaya, Çayıralan, Akdağmadeni, Saraykent, Kadışehri, and Çekerek districts in Class 1 and Class 2-Type 1 categories. The districts in question are located in the east of Yozgat Province, and due to their similar geological structure, it has been observed that the EC values in the regions close to each other are Class 1 and Class 2-Type 1.

The US salinity laboratory diagram, created using the EC and SAR values in the analysis results of 12 districts in Yozgat Province between 2016 and 2019, is given in Figure 3. Except for Çekerek, Yerköy, Şefaatli, and Kadışehri, all of the other districts are in the C2-S1 class. C2 refers to moderately saline waters. In soils with medium-drainage properties, all plants can be irrigated without the danger of salinity. Low-sodium waters (S1) are those that don't pose a risk of sodium poisoning and can be used in any type of soil. Situated in the C3-S1 zone, the districts of Kadışehri, Çekerek, and Yerköy symbolize saline waters. Irrigating C3 is not done on land with inadequate drainage. Salt-tolerant plants should be chosen in these regions. S1 refers to low-sodium waters and can be used in all soils without creating a sodium hazard. Sefaatli district is located in the C3-S2 region, which refers to salt waters. C3 is not used for irrigation on lands with poor drainage. Salt-tolerant plants such as Kadışehri, Çekerek, and Yerköy districts should be chosen. Unlike other districts, it is the only district in the S2 class, which refers to medium-sodium waters. It can be used in permeable or abundant gypsum lands.

The purpose of the regulation on the protection of groundwater from pollution and deterioration is to establish essential guidelines to preserve groundwater in its current good condition, prevent its contamination and degradation, and enhance the quality of these water sources. The quality standard for nitrates in the Annex-2 list of groundwater quality standards is 50 mg/L. When the water quality of Yozgat Province was evaluated, only the average values of Çandır district remained below this quality standard.

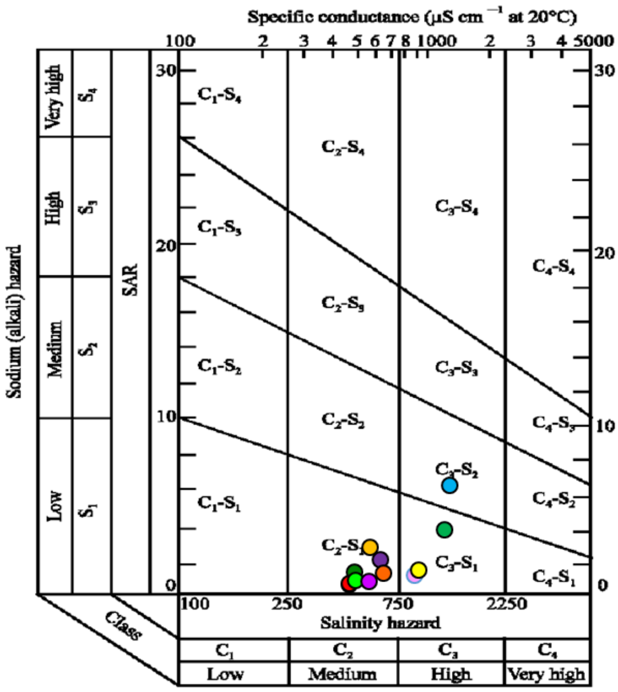

Figure 2. USA salinity laboratory diagram for well analysis in Yozgat Province.

4.2. Hydrogeochemical analysis in groundwater

4.2.1. Normality test

pH, EC, Na, K, Ca, Mg, CO_3, HCO_3, Cl, SO_4, SAR, hardness, NO_2, NO_3, NH_4, organic matter, and TDS, using the district-based average values of Yozgat Province groundwater quality data between 2016 and 2019. A normality test was applied to a total of 17 parameters. In normality test applications, if it is significant at the $p < 0.05$ level, the hypothesis is rejected, and the distribution is decided to be non-normal. However, if a $p>0.05$ value is obtained, the hypothesis is accepted, and it is interpreted that the distribution does not differ significantly from the normal distribution [35]. Data for Yozgat Province do not show a normal distribution since the p (normal) values for some of the EC, Na, K, Ca, CO_3, Cl, SO_4, SAR, NO_2, NH_4, organic matter, and TDS parameters are below 0.05.

4.2.2. Spearman correlation analysis

Hydrogeochemical assessments in the study area were conducted using Spearman correlation analysis on its groundwater. This analysis included variables such as pH, EC, Na, K, Ca, Mg, CO_3, HCO_3, Cl, SO_4, SAR, hardness, NO_2, NO_3, NH_4, organic matter, and TDS. The findings reveal a lack of significant correlation between the pH levels and other measured parameters. EC demonstrated a notably high positive correlation with Na at 0.93 and exhibited substantial positive correlations with SO_4 and TDS at 0.97, with Cl at 0.85, SAR at 0.86, and hardness at 0.91. While Na showed a significant positive correlation with Cl (0.86), SO_4 (0.88), TDS (0.84), and SAR (0.84), it only had a minimal correlation with CO_3 at 0.06. K did not show any strong correlation with the studied parameters. Ca, however, had a strong positive correlation with NO_2 (0.86) and NH_4 (0.85), whereas Mg did not show any significant correlations. CO_3 and HCO_3 generally demonstrated a negative and weak correlation with other parameters. The positive correlation between Na and Cl, SO_4, and the strong positive correlation between Cl and SO_4 in the groundwater of the Korkuteli Antalya area share similarities with the groundwater of the Yozgat region. However, the correlations of many other ions do not match [36].

4.2.3. Piper diagram

The Piper diagram presented in Figure 4 indicates that the Akdağmadeni and Kadışehri wells fall within the IV region, characterized by Ca-Mg-Cl type waters. Analytical results from wells located in the Merkez, Yerköy, Şefaatli, Sarıkaya, Sorgun, Çayıralan, Boğazlıyan, Saraykent, Çekerek, and Çandır areas show that the waters in these regions are of the Ca-Mg-HCO_3 variety. Since the samples taken from these regions are closer to each other and tend to cluster, it can be said that they have similar hydrochemistry. If we evaluate the regions in terms of cations, Ca is below 50% only in the waters of the Kadışehri region, as seen in Figure 10. In well analyses, it is seen that the Mg value is generally 50% or below. Especially the Mg percentage of the waters in the Çekerek region is quite low. If we look at Na+K values, we can say that they vary from region to region in the range of 25-75%. As for anions, CO_3+HCO_3 is quite high in many regions. It is approximately 40–50% in the Kadışehri and Akdağmadeni regions, and the lowest CO_3+HCO_3 values are observed in these regions. Cl anion values are generally below 50%; the highest Cl rate is in the Akdağmadeni region. It is seen that the SO_4 value is generally 40% and above. The presence of calcium, magnesium, carbonate, HCO_3, chloride, and sulfate in water are the parameters that determine the hardness of water [37].

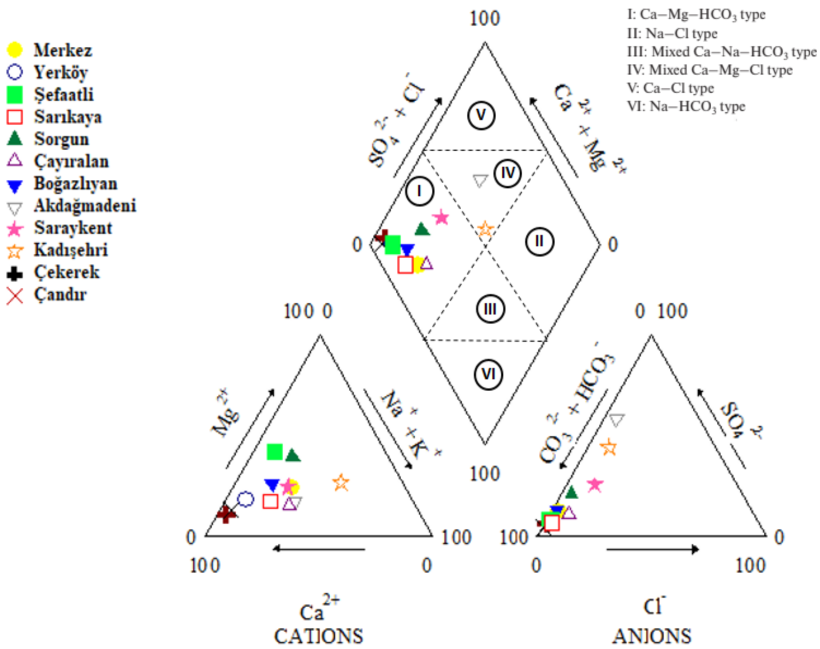

Figure 4. Piper diagram for well analysis in Yozgat Province.

Table 2. Sperman correlation analysis results of groundwater quality data of Yozgat Province.

	pH	EC	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	SAR	Hardness	NO_2	NO_3	NH_4	Org Matt.	TDS
pH	1																
EC	0.20	1															
Na	0.35	0.93	1														
K	0.02	0.32	0.14	1													
Ca	-0.29	0.60	0.38	-0.02	1												
Mg	0.26	0.72	0.68	0.64	0.02	1											
CO_3	0.50	-0.13	0.06	-0.29	-0.26	-0.27	1										
HCO_3	-0.19	0.43	0.41	0.43	-0.06	0.72	-0.50	1									
Cl	0.27	0.85	0.86	0.36	0.32	0.66	0.07	0.26	1								
SO_4	0.19	0.97	0.88	0.17	0.72	0.60	-0.13	0.30	0.74	1							
SAR	0.35	0.86	0.84	-0.04	0.66	0.41	0.19	0.09	0.65	0.92	1						
Hardness	-0.06	0.91	0.71	0.39	0.78	0.64	-0.37	0.40	0.66	0.92	0.76	1					
NO_2	0.16	0.66	0.45	0.11	0.86	0.19	-0.02	-0.16	0.38	0.77	0.81	0.78	1				
NO_3	0.27	0.33	0.25	0.52	0.13	0.25	0.12	-0.11	0.59	0.21	0.20	0.26	0.29	1			
NH_4	0.00	0.59	0.41	-0.09	0.85	0.10	-0.13	-0.05	0.22	0.74	0.79	0.71	0.91	0.04	1		
Org Matt.	0.57	0.21	0.31	-0.17	0.12	-0.08	0.14	-0.37	0.31	0.25	0.29	0.05	0.24	0.44	0.11	1	
TDS	0.19	0.97	0.84	0.36	0.68	0.67	-0.14	0.35	0.79	0.96	0.87	0.95	0.78	0.42	0.68	0.21	1

4.2.4. Clustering analysis

Clustering analysis performed for well analyses in 12 regions of Yozgat Province was classified as shown in Figure 5. Clustering of 18 parameters (pH, conductivity, Na, K, Ca, Mg, CO_3, HCO_3, Cl, SO_4, Na%, SAR, hardness, NO_2, NO_3, NH_4, organic matter, TDS) to determine the main variables affecting groundwater quality was included in the analysis. In the well analysis conducted in Yozgat Province, water characteristics can be examined in three groups. 1st Group is Sarıkaya, Çandır, Çayıralan, Çekerek, Saraykent, Akdağmadeni, Sorgun, Merkez. The 2nd Group is Boğazlıyan and Kadışehri, and the 3rd Group is Yerköy and Şefaatli regions. As can be seen when divided into three groups as a result of cluster analysis, regions close to each other generally have similar water characteristics because they have similar geology. Boğazlıyan Kadışehri region in Yozgat Province and its surroundings is one of the examples that will not be included in this generalization. It is known that Boğazlıyan region is closer to Sarıkaya-Çandır regions than Kadışehri. However, in terms of water features, it is more similar to Kadışehri than other regions. In the clustering analysis, it can be said that the regions that are generally close to each other have similar water properties due to their similar geological structure, as seen in the Sarıkaya-Çandır, Merkez-Sorgun, and Yerköy-Şefaatli regions (Figure 5).

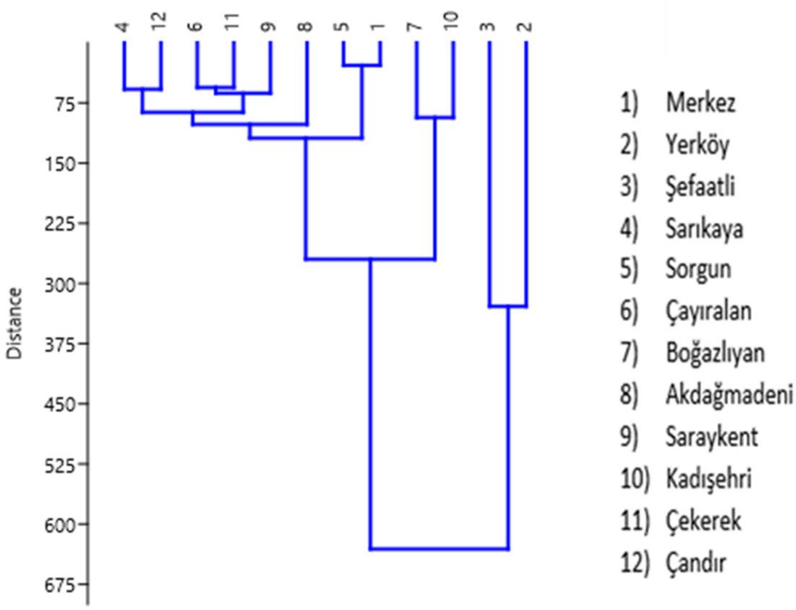

Figure 5. Clustering analysis for well analysis results in Yozgat Province.

4.2.5. Gibbs diagram

The Gibbs diagram developed by Gibbs [39] is frequently used to describe chemical processes that contribute to the evolution of the chemical components of water, such as rock dominance, evaporation dominance, and atmospheric precipitation, as well as to learn more about the sources of dissolved ions in groundwater. Gibbs diagrams were plotted using proportions of anions ($Cl/(Cl+HCO_3)$) and cations ($Na+K/(Na+K+Ca)$) opposed to the concentration of TDS. The interaction between the minerals in the aquifer and the groundwater was revealed by the Gibbs diagram of the results of water sample analyses (Figure 6), which showed that the rock dominance process governed the chemical composition of groundwater.

It shows that the groundwater in the region originates from the chemical decomposition of rock-forming minerals, which control the main mechanism in water chemistry [36]. Hydrogeological and hydrogeochemical properties of surface and groundwater in the east of Şefaatli district of Yozgat Province were examined by Şener and Şener [38]. When the parameters of the region's waters were placed on the Gibbs diagram, it was concluded that all water samples were in the rock dominant class, as found in this study.

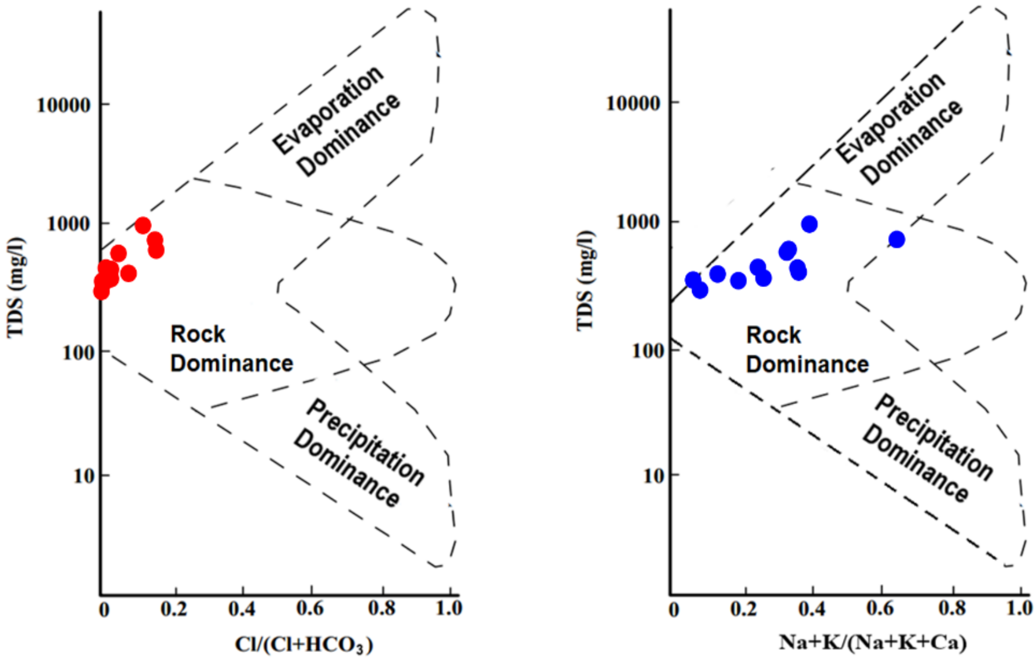

Figure 6. Gibbs's diagram showing the controlling mechanisms for groundwater chemistry of Yozgat Province.

4.2.6. Factor analysis/PC analysis

As a result of the principal components analysis, variance percentages were fixed at Factor 7. As a result of the analysis, the values of a total of seven factors are given in Table 3. The most effective ions in Factor 1 are HCO_3 and Mg in the positive direction, as seen in Table 3. In factor 2, Ca and Cl ions show the most positive effect. Considering factor 3, the most negatively active ion is Ca. The scatter chart of the factor analysis and principal component analysis conducted for the Yozgat region shows the amount of variance explained by each factor. In this study, 12 parameters (pH, K, Ca, Mg, CO_3, HCO_3, Cl, % Na, SAR, hardness, NO_2, NO_3) were analyzed. Before the analysis, the data series were normalized, and data with high correlations and data with very low variance were removed. The first factor (PC) shows the highest variance, and the last factor shows the lowest variance. As a result of the analysis, the highest variance is 41% in factor 1, and this factor constitutes 41% of the total variance. Factor 2 accounts for 32% of the total variance, and factor 3 accounts for 19% of the total variance. The remaining factors each account for less than 10% of the total variance (Figure 7).

Table 3. Factor values.

Parameters	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
pH	-0.00030	-0.41797	0.00228	0.00503	-0.00051	0.01064	0.01285
K	0.02862	0.00933	0.03719	-0.06131	0.14471	0.02717	0.97843
Ca	0.04820	0.79810	-0.52672	-0.17604	-0.02971	0.01315	0.00674
Mg	0.32494	0.06095	0.15926	0.27284	0.71099	0.36509	-0.10772
CO_3	-0.00472	-0.00057	0.00501	0.01398	-0.01457	0.00494	0.11244
HCO_3	0.90384	-0.19464	-0.11068	-0.27092	-0.23645	-0.05913	0.00042
Cl	0.19472	0.28682	0.27824	0.46050	0.04300	-0.76622	0.02573
% Na	0.12163	0.17791	0.12373	0.60952	-0.56260	0.47623	0.08813
SAR	0.01272	0.03797	-0.00569	0.06883	-0.03943	0.08907	0.06012
Hardness	0.14551	0.22551	-0.06427	0.06716	0.29075	0.14613	-0.06074

NO_2	0.00959	0.00292	-0.00079	0.00088	0.00165	0.00781	0.00635
NO_3	0.01675	0.39387	0.76593	-0.47367	-0.10999	0.13755	-0.04941

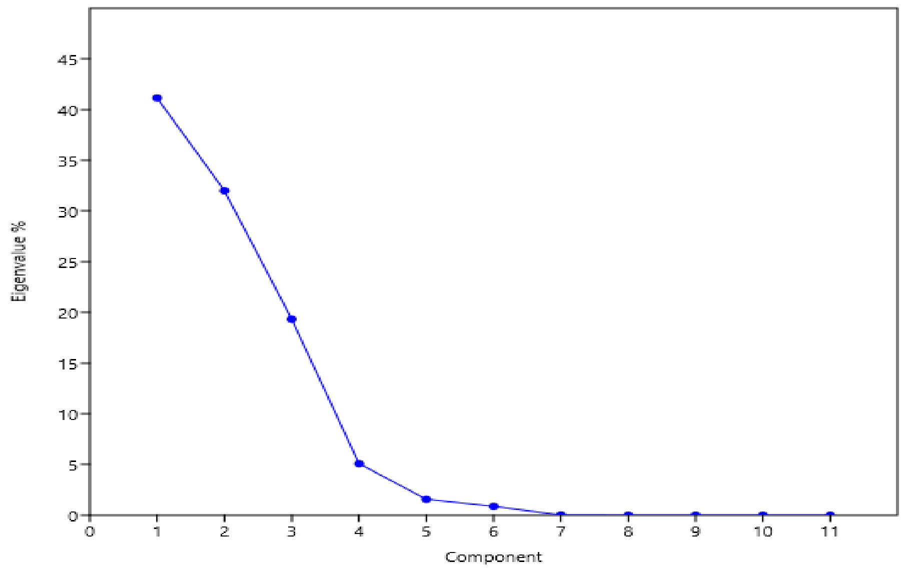

Figure 7. Scree test graph

4.2.7. Relationships between cations and anions in groundwater samples

The abundance states of ions in the study area are related to hydrogeochemical processes in the aquifer system. Different diagrams were prepared to explain these processes, and comments were made based on these diagrams. The relationships between anions and cations are given in Figure 8. Between Na and Cl, R^2 is 0.87 (Figure 8a). The R^2 value in the Na-SO_4 relationship given in Figure 8b is 0.78. Na has a stronger relationship with SO_4 compared to Mg and the least related ions are Mg and SO_4 ions. It can be seen in Figure 8c that the R^2 value in the relationship between Mg and HCO_3 is 0.88. As seen in Figure 8d, the Mg-SO_4 relationship is quite low with the coefficient value (R^2) of 0.56. There is a strong relationship (R^2 = 0.98) between Ca+Mg and HCO_3+ SO_4 (Figure 8e). In general, carbonates and silicates are the main sources of mineralization in water. The Ca+Mg and HCO_3+SO_4 diagrams show the dominant weathering types in groundwater. When the anion-cation relationships in the study area are evaluated, the strongest relationship is seen between Ca+Mg and HCO_3+SO_4 (R^2 = 0.98).

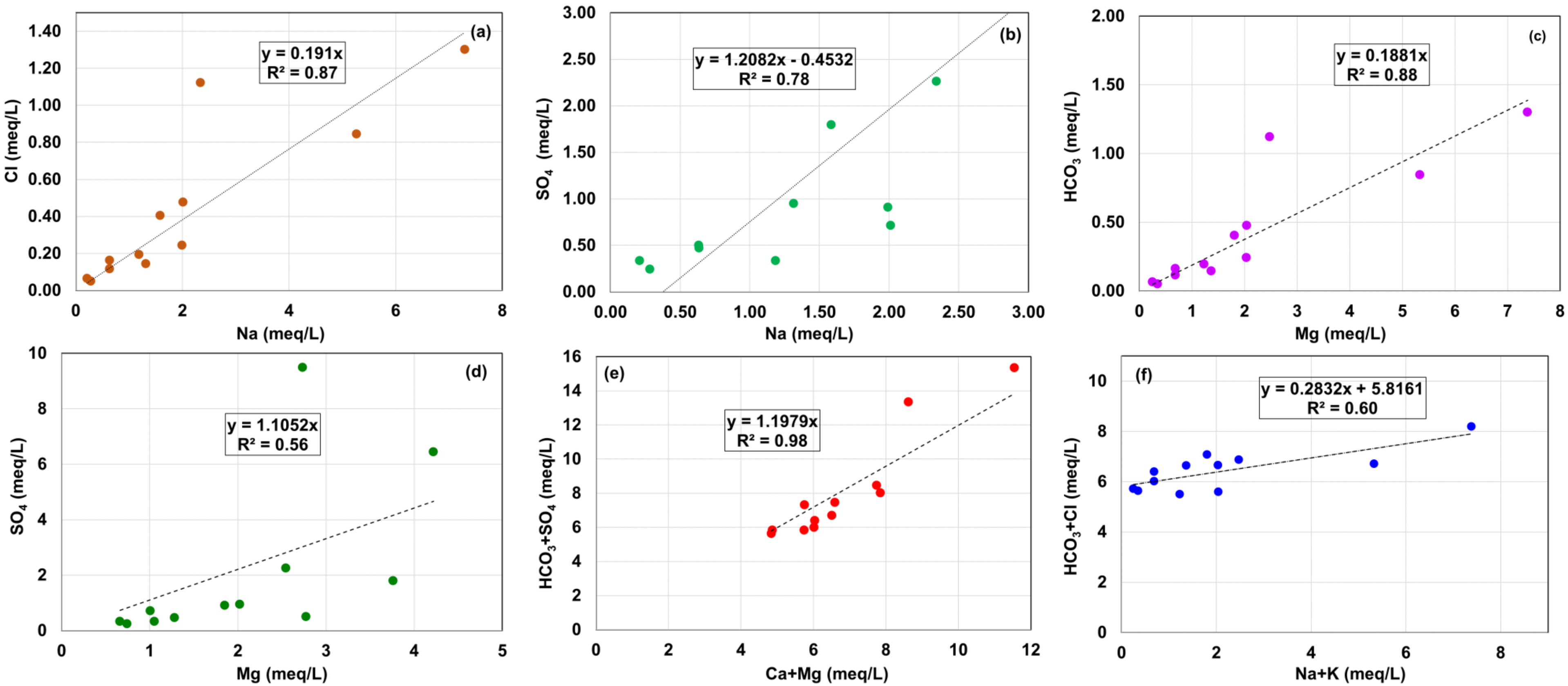

Figure 8. Anion-cation relationships in groundwater samples

5. Discussion and Conclusion

In this study, it was aimed at evaluating the hydrogeochemical data on the groundwater quality of Yozgat Province and its surroundings. The analysis results of water samples were obtained from the 12th Regional Directorate of State Hydraulic Works. pH, EC, Na, K, Ca, Mg, CO_3, HCO_3, Cl, SO_4, % Na, SAR, hardness, NO_2, NO_3, NH_4, organic matter, and TDS parameter analysis results were used in water quality and hydrogeochemical evaluation. The groundwater quality of the region was evaluated according to TS 266 and the Regulation on Water for Human Consumption, and its suitability for use and agricultural irrigation was evaluated according to the US Salinity Laboratory Diagram and the Regulation on the Protection of Groundwater against Pollution and Deterioration. Hydrogeochemical evaluation of water resources was examined according to Sperman correlation, Piper diagram, Gibbs diagram, cluster analysis, factor analysis, and anion-cation relationships.

As a result of the evaluation according to TS 266 and the Regulation on Water Intended for Human Consumption, average pH values were found to be between 6.5 and 9.5 limit values in all water samples. The TDS value of water samples is a parameter related to EC and represents an average of 69% of the conductivity. The variation in proportional relationships between EC (120–5600 μS/cm) and TDS (0.05–2.5%) may be associated with the type of salinity and the proportionality coefficient, which ranges from 2.22 to 3.16 [40]. On the other hand, solutions with higher concentrations of divalent ions exhibit lower electrical conductivity compared to those with monovalent ions at similar ionic strengths, highlighting the effect of ion pairing. Due to significant errors in high salinity ranges, a specialized correlation should be developed to accurately represent saline waters with similar chemical compositions [41].

The average values of NH_4 in Şefaatli district, SO_4 in Yerköy and Şefaatli districts, and NO_3 in Boğazlıyan, Kadışehri, and Çandır districts were observed to be above the limit values according to the TS 266 and the Regulation, and it was determined that it was not suitable for use as drinking water due to presence of nitrate. Within the scope of the regulation on the protection of groundwater against pollution and degradation, the quality standards for nitrates are stated as 50 mg/L in the Annex-2 list of groundwater quality standards. When the water quality of Yozgat Province was evaluated, only Çandır district remained below this quality value.

As a result of the normality test applied to the sample analysis results taken from the region, an evaluation was made with Spearman correlation since the results did not show a normal distribution. The highest correlation relationships were observed between EC, SO_4, and TDS with a coefficient of 0.97. On the other hand, a strong positive correlation was observed between conductivity and Cl, SAR, and hardness at values of 0.85, 0.86, and 0.91, respectively. The Piper diagram created with the analysis results of a total of 12 districts revealed that Akdağmadeni and Kadışehri groundwaters are Ca-Mg-Cl type waters. The waters in the Merkez, Yerköy, Şefaatli, Sarıkaya, Sorgun, Çayıralan, Boğazlıyan, Saraykent, Çekerek, and Çandır regions are Ca-Mg-HCO_3 type waters. It was understood that the samples taken from these regions had similar chemical structures due to the similar geological structure of the districts and their tendency to cluster. In the study conducted by Şener and Şener [38], the hydrogeological and hydrogeochemical properties of surface and groundwater in the east of Şefaatli district of Yozgat Province were examined. It was concluded that it is in the Na-Ca-HCO_3, Ca-Mg-HCO_3, and Ca-Mg-HCO_3-SO_4-type water facies. The findings obtained in this study support the results obtained in our study.

Cluster analysis was performed to identify the main variables affecting groundwater quality. In the clustering analysis, it is seen that the regions that are close to each other have similar water characteristics due to their similar geological structure, as seen in the Sarıkaya-Çandır, Merkez-Sorgun, and Yerköy-Şefaatli regions. Based on the Gibbs diagram, it is evident that all the waters within the area fall under the category dominated by rock interactions. This indicates that the region's groundwater is derived from the chemical breakdown of minerals that form rocks, which dictate the primary processes influencing water chemistry. According to factor analysis/Principal Components analysis, Factor 1 has the highest variance (41%). The variance of Factor 2 was 32% and Factor 3 was 19%, and each of the remaining factors constituted less than 10% of the total variance. In Factor 1, the most effective ions were HCO_3 and Mg in a positive direction. In Factor 2, Ca and Cl ions showed the most influence in a positive direction. In factor 3, the most negatively active ion is Ca.

When the anion-cation relationships in the study area are evaluated, the strongest relationship is seen between Ca+Mg and HCO_3+SO_4 (R^2 = 0.87). When the relationship between Ca+Mg and HCO_3+SO_4 was evaluated, it was concluded that carbonate dissociation dominated the chemical development of groundwater in the study area. Additionally, it has been observed that Na has a stronger relationship with SO_4 compared to Mg. Among the ions evaluated within the scope of the study, the least related ions are Mg and SO_4 ions. It was concluded that carbonate weathering played a dominant role in the chemical development of groundwater in the study area. The relationship between HCO_3+Cl and Na+K is illustrated in Figure 14f, showing a low correlation with an R^2 value of

0.59. These correlations are likely due to rock-water interactions and ion exchange processes within these groundwater systems. Ates et al. [3] found strong correlations between Ca and Mg, and HCO_3, indicating that Ca and Mg originate from the weathering of carbonate rocks (calcite, dolomite, and aragonite). In the study by Imbulana et al. [42], TDS showed a stronger correlation with Cl (R = 0.556–0.797) than with other major ions such as Ca, SO_4, Na, HCO_3, and Mg. Additionally, notable strong correlations were observed between Na and Cl, Ca and SO_4, Mg and HCO_3, as well as between Ca and Cl, and SO_4 and Cl. The study by Sunkari et al. [43] identified Na-HCO_3-Cl as the dominant water type in the area, alongside various mixed water types. The hydrochemical composition of river water and groundwater in the Genggahai Basin is primarily influenced by HCO_3, resulting from rock weathering and dissolution. The dominant cations are Ca and Na. The presence of evaporite, carbonate, and silicate minerals in the basin significantly affects the water's hydrochemical profile [44].

With the US Salinity Laboratory Diagram, all of the districts except Çekerek, Yerköy, Şefaatli, and Kadışehri are in the C2-S1 class. Kadışehri, Çekerek, and Yerköy districts are located in the C3-S1 region. It has been observed that Şefaatli district is in the C3-S2 class. According to the US Salinity Laboratory Diagram, it has been observed that groundwater in the region can generally be used for irrigation purposes. The main water source of the Bafra Plain is the Kızılırmak River, one of the saltiest water sources in the country, classified as C3-S1 [45]. Samples taken from Kufi Stream, the primary surface water feeding Işıklı Lake, were classified as C3-S1 [46]. According to the US Salinity Laboratory Classification system, which uses EC and sodium adsorption rate (SAR) values for classification, it has been confirmed as C3-S1 class [47]. The water quality in this region has been reported to range from C3-S1 to C4-S3 [48].

This study evaluated the hydrogeochemical data on groundwater quality in Yozgat Province and its surroundings, utilizing analyses from the 12th Regional Directorate of State Hydraulic Works. It was determined that the groundwater quality fell within acceptable ranges for human consumption and agricultural irrigation according to TS 266 and international regulations, with analyses showing diverse water types and mineral influences predominantly dictated by rock-water interactions and ion exchange processes. The results obtained within the scope of this study can be used in studies related to water management plans and the principles of the study area. Our findings also suggest that groundwater can be used more efficiently in the region, contributing to the environment and economy.

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