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Research Article

Statistical Analysis of the Environmental Impacts of Brine Discharged by the Tuz Gölü Natural Gas Storage Project on Tuz Gölü

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Abstract
Tuz Gölü Natural Gas Storage Project is one of the most crucial projects developed by BOTAŞ within the framework of ensuring energy supply security. Within the scope of this project. artificial caverns are created for the storage of natural gas and for this purpose. salt layers located 700 to 1500 meters below the ground are leached with fresh water. The brine released as a result of the leaching is discharged into the Tuz Gölü through a 40 km pipeline. This study aims to analyze and interpret the effects of this discharge on the Tuz Gölü. pH, Electrical Conductivity, Salinity, Dissolved Solids Suspended Solids, Sulfate, Chloride Alkalinity, Nitrate, Nitrite, Ammonium Nitrogen, Sodium, Magnesium, Calcium, Oil and Gress parameters were analyzed to determine the water quality in the brine samples taken monthly from the brine discharge point from 2015 when the discharge started until 2023. Related measurements were taken monthly within the scope of this project and analyzed by an accredited laboratory. SPSS 25.0 for Windows package program was used for data analysis. Mean and standard deviation values were used to describe the data. Kolmogorov Smirnov normality test was performed to confirm conformity of the research parameters to the standard normal distribution. The present study aims to provide an environmental impact prediction for future projects.

Tuz Gölü Doğal Gaz Depolama Projesi Tarafından Deşarj Edilen Tuzlu Suyun Tuz Gölü Üzerindeki Çevresel Etkilerinin İstatistiksel Analizi

Anahtar kelimeler
Doğal Gaz Depolama, Tuz Gölü, Çevresel Etki

Özet
Tuz Gölü Doğal Gaz Yer Altı Depolama Projesi ülkemiz enerji arz güvenliğinin sağlanması hedefi kapsamında BOTAŞ tarafından yürütülmekte olan en önemli projelerden biridir. Proje kapsamında doğal gazın depolanması amacıyla yapay mağaralar (kaverna) oluşturulmakta ve bu amaçla yerin 700 ile 1500m altında bulunan tuz tabakaları tatlı su ile çözülmektedir. Çözme sonucu açığa çıkan tuzlu su ise yaklaşık 40km boru hattı ile Tuz Gölü'ne deşarjı sağlanmaktadır. Bu çalışmanın amacı söz konusu deşarjın Tuz Gölü'ne etkilerinin analiz edilmesi ve yorumlanmasıdır. Bu amaçla deşarjın başladığı 2015 yılından 2023 yılına kadarki tuzlu su deşarj noktasından proje kapsamında kurumca aylık olarak alınan tuzlu su örneklerinde su kalitesinin belirlenmesi amacıyla pH, Elektirksel İletkenlik, Askıda Katı Maddeler, Tuzluluk, Çözünmüş Katılar, Askıda Katı Maddeler, Alkalinite, Sülfat, Klorür, Nitrat, Nitrit, Amonyum Azotu, Sodyum, Magnezyum ve Kalsiyum parametreleri incelenmiştir. Çalışma kapsamında analiz sonuçları istatistiki olarak değerlendirilmiş, verilerin analizinde SPSS 25.0 for Windows paket programı kullanılmıştır. Verilerin tanımlanmasında ortalama ve standart sapma değerleri kullanılmıştır. Araştırma parametrelerinin standart normal dağılıma uygunluğunun test edilmesi için Kolmogorov Smirnov normallik testi uygulanmıştır. Çalışma ile bundan sonrasında yapılacak projeler için bir çevresel etki öngörüsü sağlanması hedeflenmiştir.

1. Introduction

Natural gas storage is of great importance for countries that are dependent on foreign energy resources. Natural gas storage is a common practice worldwide. and storage projects are given importance in our country to meet the increasing consumption and demand. Natural gas consumption increases yearly due to increasing population and development levels.

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Thus, natural gas is stored to meet seasonal. daily and hourly peak demands. protect system regulation due to supply and demand imbalances, be an alternative against interruptions in case of breakdown maintenance and stabilise price fluctuations. In addition, as a requirement of the "Natural Gas Market Law" numbered 4646. at least 10% of the natural gas imported throughout the country must be stored (Figure 1). This rate is determined as 20% by European Union standards. According to EMRA data. Turkey's import amount was approximately 60 billion (60.044.873.569) m^3 in 2022 [1].

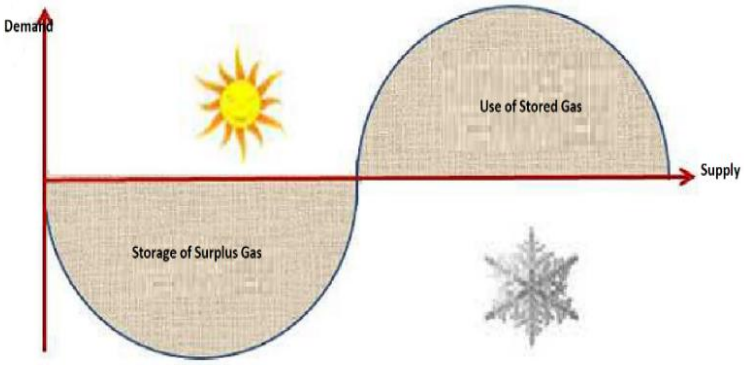

Figure 1. Purpose of natural gas storage [2]

The Tuz gölü Natural Gas Storage Project. one of the projects carried out for the supply security of our country. is an example of natural gas storage in salt structures among storage types. Within the scope of the project. which is being carried out in Sultanhanı District of Aksaray. the salt layers located approximately 600 to 700 m below the ground are melted with fresh water and the natural gas taken from the Kayseri-Konya-Seydişehir main transmission line, which is approximately 23 km away from the project area. is stored in the opening formed by leaching with fresh water and is supplied to the national grid from the same line in case of need. The fresh water required for the leaching process is supplied from Hirfanlı Dam through a pipeline of approximately 120 km and the saline water released from the leaching process is discharged into Tuz Gölü through a 40 km pipeline. The present study aims to analyse the environmental impacts of the water discharged to Tuz Gölü during the project. Within the scope of the studies on the discharge of saline water during the preparation of the EIA Report for the project. the "Niggle Diagram" which has been used for many years in the basin and irrigation water projects of DSI and drinking water projects of Iller Bank (see Figure 2). was used to analyse whether the saline water formed as a result of the dissolution process shows similar characteristics with Tuz gölü.

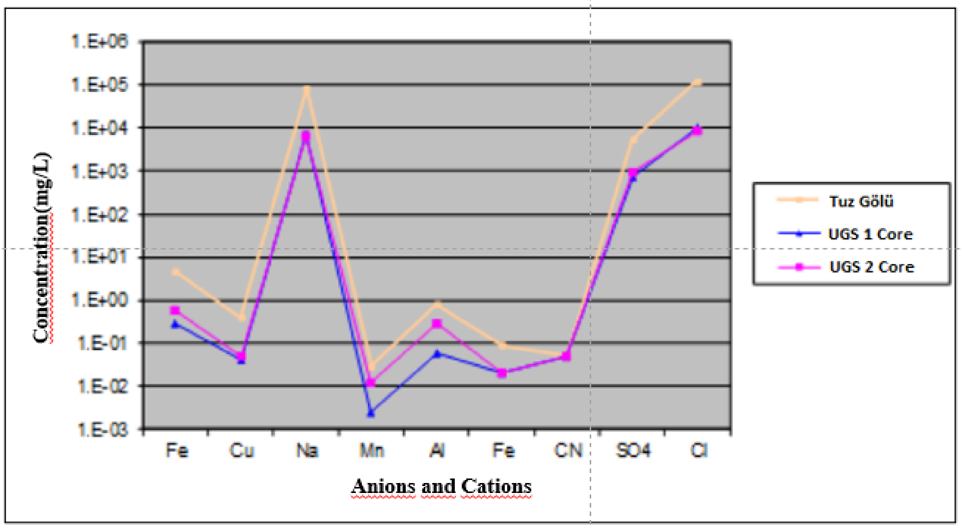

Figure 2. Niggle diagram [3]

When the diagram is analysed. it is understood that the anion-cation changes of the cores obtained from the study area and the water samples taken from Tuz gölü coincide with the anion-cation changes. It is stated that it is possible to infer that the water formed as a result of the dissolution of the water sample taken from Tuz Gölü and the core samples taken for analysis from the project site in water come from the same source [3]. In the present study. it was aimed to evaluate the effects of the discharge by comparing the water samples taken monthly from the discharged water with the parameters of Tuz gölü.

2. SOURCE INVESTIGATION

2.1. Natural Gas Storage in the World

Natural gas storage operations in the world started in the early 1900s. In 1909. the U.S. Geological Survey recommended underground storage of surplus natural gas, while the first successful natural gas storage was realised in Canada in 1915 [4].

2.2. Natural Gas Storage Methods

There are three different methods for underground storage of natural gas as follows: storage in depleted reservoirs, storage in salt formations and storage in aquifers (Figure 3). The natural gas storage method generally preferred in the world is depleted reservoirs. Since these fields contain natural gas years ago and are depleted structures, gas loss is minimal and can be used as a natural storage. Salt formations and storage in aquifers are few in number because they require costly operations. Not every salt layer or aquifer discovered may be suitable for natural gas storage. The main criterion at this point is to ensure impermeability [2].

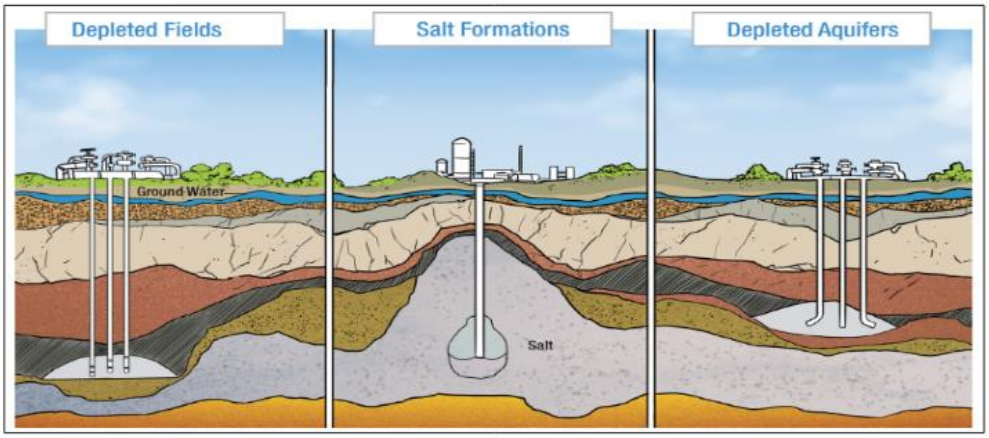

Figure 3. Illustration of natural gas storage methods [3]

2.2.1. Natural gas storage in salt structures

Hydrocarbon storage in salt structures was applied in Germany during the First World War. This method is based on the principle of gas storage in cavities formed by dissolving underground salt layers by injecting fresh water. This method. also called solution mining. was initially used for salt or mineral production. but is now widely used for gas storage. There are some important factors for the storage of natural gas or other hydrocarbon derivatives in salt structures: the presence of a salt layer with appropriate depth. the salt layer having sufficient thickness. the presence of the water source needed for the thawing process and the suitable environment for the disposal/discharge/disposal of the brine that will be released during the thawing process [5].

2.2. Tuz gölü Natural Gas Storage Project

The Tuz gölü Natural Gas Storage Project, whose construction works were started in the Sultanhanı district of Aksaray province in 2011. is a project that has an important role in ensuring the energy supply security of our country by BOTAŞ. Phase 1 of the project was completed by the end of 2021 and currently operates with a working gas capacity of 1.2 billion Sm^3 and a daily reproduction capacity of 40 million Sm^3. Phase 2, initiated to increase the capacity within the scope of natural gas storage activities is ongoing and will reach a total capacity of 5.4 billion Sm^3 of working gas and 80 million Sm^3 of daily back production capacity at the end of the project. For this purpose, several processes are being carried out to create caverns (artificial caves) for storage. The first of these is drilling activities. The drilling activity, which is one of the pre-dissolution stages of the project, is carried out to reach the salt layer, which starts approximately 700 m below the ground and reaches approximately 1500 meters, and 1500 meters of drilling is carried out for each cavern. After the well profile is completed after the drilling operations, preparations for the leaching operation begin. Leaching is the name given to the process of dissolving the salt underground with fresh water and taking the solution to the surface and creating an artificial cave by continuing the process. For the process, a 120 km fresh water line has been constructed from Hirfanlı dam and the water coming to the facility is pressurised by means of leaching pumps and sent to the wells and leaching starts. The 10 3/4" and 7" pipes to be used in the leaching process are lowered into the well, as shown in Figure 4. Two different leaching methods are used to create the cavern. These are direct and indirect leaching. In direct leaching, fresh water is pressurised from the inner 7" pipe and brine is taken from the space between 7" and 10 3/4" pipes. In indirect leaching, fresh water is pressurised through the space between 10 3/4" and 7" pipes and brine is taken from 7**.**"

The brine released as a result of the dissolving process is first taken into the pools in the facility. Here, the insoluble solids in the brine are allowed to precipitate. In this way, it is aimed to minimise the amount of solids during the discharge, preventing clogging in the pipeline and preventing the discharge of solids into the Tuz gölü (see Figure 5). After precipitation, the salty water is discharged to Tuz gölü through a pipeline of approximately 40 km.

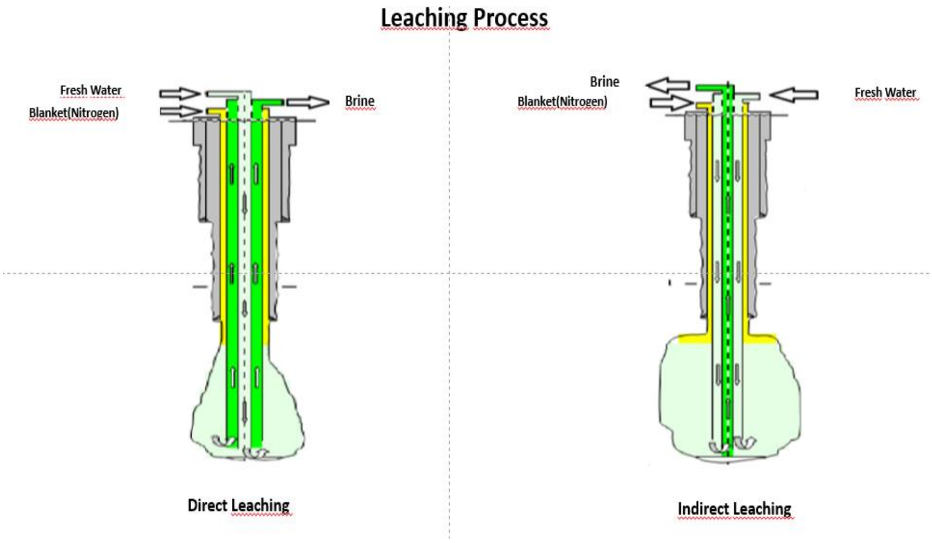

Figure 4. Leaching method [3]

Figure 5. Salt-water discharge line

The precipitated solids are sent to cement factories and utilised as additional raw material/fuel and disposed of. Before this study. a literature search was carried out and it was observed that there are many studies on natural gas storage, but the studies are generally on technical parameters and there is no study on the environmental effects of salt water discharge. This situation shows a need for a detailed study on this subject.

2.3. Tuz gölü Basin

The area described as Tuz Gölü Basin is located within the borders of Aksaray, Konya, and Ankara provinces and is also referred to as Şereflikoçhisar Tuzlası, Koçhisar Lake. and Tuz Gölü in different sources. It is located 905 meters above sea level [6]. Tuz Gölü has the status of Special Environmental Protection Area and a part of the area is considered as a Grade I Protected Area. Tuz Gölü is home to many species classified as endemic species that is species not found anywhere else in our country. The lands around the Tuz gölü also have a salty structure. The rivers carrying water to the Tuz gölü carry the salt they bring from the surrounding land to the lake, which is in the lowest part of the closed basin. As the lake water evaporates due to high temperature, the salt precipitates and remains [7]. Konya Closed Basin is located in the least rainfall region of Turkey regarding precipitation. When the precipitation map of the General Directorate of Meteorology is examined, it is clearly understood that it is one of the regions with the lowest amount of precipitation per square meter, which means that the water volume of Tuz Gölü decreases considerably during the year and over the years.

The water discharged within the scope of the Tuz gölü Natural Gas Underground Storage Project is important at this point. Thanks to the discharge to the lake, which has low precipitation and high evaporation, the water volume is contributed and thus the drying of the lake is prevented. In this study, to understand the effect of the discharged water on the lake. it was aimed to compare the sample taken from the discharged water and the existing parameters of the lake.

3. MATERIAL AND METHOD

Within the scope of this study, it is aimed to investigate the effect of salt water discharged to Tuz gölü on Tuz gölü In this context. pH. Electrical Conductivity, Salinity, Dissolved Solids Suspended Solids, Ammonium Nitrogen, Alkalinity, Sulphate, Chloride, Nitrate, Nitrite, Sodium, Calcium and Magnesium parameters were analysed to determine the water quality in the brine samples taken from the brine discharge point from 2015 when the discharge started until 2023. Related measurements were taken monthly within the scope of the project and analysed by the accredited laboratory. The relevant analysis result data were analysed and the discharge of each year was statistically analysed within itself and over the annual averages, and it was evaluated whether there was a significant difference with Tuz gölü and whether it had any pollutant effect. SPSS 25.0 for Windows package programme was used to evaluate the related parameters. Mean and standard deviation values were used to describe the data. The "Kolmogorov Smirnov" normality test was used to determine whether the research parameters fit the standard normal distribution. In addition Magnesium, Iron, Total Chromium, Sodium, Lithium, Aluminium, Manganese, Copper, Zinc, Boron, Cobalt, Nickel, Arsenic, Cadmium, Lead, Cadmium, Lead, Cadmium, Lead, Mercury analysis results for the years 2022 and 2023. which can be evaluated as pollution parameters even though they are not heavy metals and heavy metals, were also evaluated by comparing with Tuz gölü.

3.1. Statistical Method

3.1.1 Statistical Package for the Social Sciences (SPSS)

Although SPSS is mostly used in the field of social sciences, it is used to obtain data for many sectors. such as health and education sectors. In addition, it is a widely used method for evaluating the survey results obtained. SPSS is used for statistical analysis and is used to extract data that are homogeneous or suitable for normal distribution and then to analyse the relevant data, so that complex and challenging to process data can be evaluated more easily. The data can also be converted into a graph to make sense of it.

3.2. Normal Distribution Tests

Firstly. it should be determined whether the quantitative variable fits the normal distribution. The tests commonly used to test this situation are Shapiro Wilk and Kolmogorov Smirnov tests. The factor considered in the selection of these tests is the sample size. If the sample size: $n<30$, the Shapiro Wilk test is used, while if the sample size is greater than or equal to 30, the Kolmogorov Smirnov test can be used. For both tests, the test result $p>0.05$ means that the variable shows normal distribution characteristics, and $p<0.05$ means that the variable does not show normal distribution characteristics.

3.2.1. Comparison of means and non-parametric tests

One sample t-test, in other words, one sample t-test is used to determine whether there is a statistically significant difference between the mean value of a quantitative variable and the sample mean value. Some assumptions are made before starting the test; the sample must be randomly selected from the population. the variable to be analysed must be at least interval scale and it must be suitable for normal distribution [8]. The accuracy of the assumptions is important for the analysis to give correct results. The first hypothesis of the test. H0: There is no difference between the mean of the population and the mean of the sample. The second hypothesis. H1. is that there is a difference between the population mean and the sample mean. As a result, if the p-value is greater than 0.05. the HO hypothesis is significant, while if the p-value is less than 0.05. the H1 hypothesis is confirmed. To test whether there was a statistically significant difference between the mean of a quantitative variable of two data groups that were not dependent on each other, independent samples t-test was performed. The assumptions made before starting the test are that the sample is randomly selected from the universe. the variable to be analysed is at least interval scale and suitable for normal distribution, the variance of the groups is equal and the two groups are independent from each other [9, 10].

In the test phase, whether the variances are equal or not is tested with "Levene's Test for Equality of Variances." If the variances are not equal, two test values (p and t) are formed and compare the means of a variable of two groups. Some assumptions are made before starting the test; the variable to be analysed must be at least interval scale, the groups must be independent and suitable for normal distribution and the variance of the groups must be equal.

3.2.2. Mann-Whitney U test

Mann-Whitney U Test is a non-parametric test of the t-test in independent groups mentioned in the previous section. This test is used in cases where the aforementioned assumptions are not met and is used to test whether there is a statistically significant difference between two independent groups. In this test, all data are sorted from largest to smallest, and the data are given a rank number starting from one, After ranking, the data are divided into two groups for comparison, and the mean rank of the group rank numbers is taken [8, 9]. In other words, the test compares the rank averages of the groups, not their medians. In summary, the way the test works is to compare the mean rank of two independent groups. The assumption of the test is that the groups are independent from each other, at least in rank scale. The first hypothesis of the test. H0: There is no difference between the scores of the two groups. The second hypothesis, H1: There is a difference between the scores of the two groups. As a result, if the p-value is greater than 0.05. the HO hypothesis is significant. while if the p-value is less than 0.05. the H0 hypothesis is rejected [11-15].

3.3. Experimental Studies

Within the scope of the present study, annual averages were taken based on the monthly measurement results of the discharged brine between 2015-2023. The result parameters were compared with the parameters taken from the Tuz gölü itself and it was examined whether there was a significant difference between the parameters. Within the scope of this investigation, the relevant results were obtained by considering both the annual and the average results of all years. SPSS 25.0 for Windows package programme was used for data analysis. Mean and standard deviation values were used to describe the data. Kolmogorov Smirnov normality test was performed to confirm conformity of the research parameters to the standard normal distribution. Since the distribution of all parameters differed from the standard normal distribution as a result of the test ($p<0.05$). nonparametric tests were used. Mann-Whitney U test was performed to determine significance of the difference between the two groups. Table 4.11 Spearman's rho correlation analysis was performed in the correlational screening test due to deviations from linearisation [16]. All tables from Table 1 to Table 10 are Mann-Whitney U test, which is a nonparametric analysis of the difference between two groups. The test value is used to find the p-value by looking at the standard tables. If the p-value is below the 0.05 limit. the differences are significant, if above. they are not significant. The mean values of all measurements between 2015-2023 for Tuz gölü and sample measurements and the results of the difference analysis are given in Table 1.

Table 1. Results of the difference analysis of all measurements between 2015 and 2023 with the mean values of Tuz gölü and sample measurements

Paramaters	Unit	Sampling				Test Value	p-value
		Sample average		Tuz gölü			
		Average	Standard Deviation	Average	Standard Deviation		
pH		6.54	0.60	7.71	0.00	86.000	0.000
Electricity_conductivity	µs/cm	55063.10	62979.35	100000.00	0.00	1870.500	0.000
Salinity	%o	95.98	34.29	86.00	0.00	3577.500	0.336
Dissolved_solids	mg/L	54978.87	17737.18	50000.00	0.00	3397.000	0.010
Suspended_materials	mg/L	83.61	114.65	105.90	0.00	2264.000	0.000
Sulphate	mg/L	2947.54	1975.67	9670.00	0.00	86.000	0.000
Chloride	mg/L	163791.09	34693.91	194139.00	0.00	603.000	0.000
Alkalinity	$CaCo_3$/L	116.72	32.60	159.60	0.00	86.000	0.000
Nitrate	mg/L	3.17	16.12	0.66	0.00	2467.000	0.000
Nitrite	mg/L	0.05	0.10	0.07	0.00	1118.000	0.000
Ammonium_nitrogen	mg/L	0.16	0.20	0.97	0.00	87.000	0.000
Sodium	mg/L	98709.65	32204.66	139581.00	0.00	522.000	0.000
Magnesium	mg/L	37.21	17.95	4832.00	0.00	0.000	0.000
Calcium	mg/L	1222.47	400.95	672.49	0.00	86.000	0.000
Oil_grease	mg/L	10.00	0.00	.	.	-	-

According to the results of the analyses, dissolved solids and calcium values of the sample averages are statistically significantly higher than the average of Tuz Gölü since $p<0.05$. However, pH, electrical conductivity, suspended matter, alkalinity, sulphate, chloride, nitrate, nitrite, ammonium nitrogen, sodium and magnesium averages are statistically significantly lower than the average values of Tuz Gölü since $p<0,05$. According to these results, it was seen that the levels of pollutants were below the average of Tuz Gölü and this difference was significant. When all parameters were evaluated within each other, no significant parallelism have been found between them. However, calcium and sodium values show parallelism in all month and year averages. The increase in sodium ion causes an increase in the amount of calcium. For 2015, the differences between the measured values and the values of Tuz gölü and the results of the difference analysis are given in Table 2.

Table 2. Differences and difference analysis results between measured values and Tuz gölü values for 2015

Paramaters	Unit	Sampling				Test Value	p-value
		Sample average		Tuz gölü			
		Average	Standard Deviation	Average	Standard Deviation		
pH	-	6.89	0.32	7.71	0.00	0.000	0.000
Electricity_conductivity	µs/cm	10000.00	0.00	100000.00	0.00	0.000	0.000
Salinity	%o	86.00	0.00	86.00	0.00	72.000	1.000
Dissolved_solids	mg/L	50000.00	0.00	50000.00	0.00	72.000	1.000
Suspended_materials	mg/L	13.83	7.47	105.90	0.00	0.000	0.000
Sulphate	mg/L	2644.25	388.03	9670.00	0.00	0.000	0.000
Chloride	mg/L	151331.00	22647.22	194139.00	0.00	0.000	0.000
Alkalinity	$CaCo_3/L$	117.22	13.47	159.60	0.00	0.000	0.000
Nitrate	mg/L	2.56	4.00	0.66	0.00	60.000	0.457
Nitrite	mg/L	0.03	0.02	0.07	0.00	12.000	0.000
Ammonium_nitrogen	mg/L	.024	0.23	0.97	0.00	0.000	0.000
Sodium	mg/L	101185.83	25355.99	139581.00	0.00	12.000	0.000
Magnesium	mg/L	32.95	11.72	4832.00	0.00	0.000	0.000
Calcium	mg/L	942.32	298.33	672.49	0.00	12.000	0.000
Oil grease	mg/L	10.00	0.00	.	-		-

In 2015, salinity, dissolved solids and nitrate values were similar in the sample and Tuz Gölü averages and the differences were not statistically significant since $p>0.05$. The values of all other measured values for all months in 2015 were statistically significantly higher for Tuz Gölü since $p<0.05$. For 2016, the differences between the measured values and Tuz Gölü values and the results of the difference analysis are given in Table 3.

Table 3. Differences and difference analysis between measured values and Tuz gölü values for 2016

Paramaters	Unit	Sampling				Test Value	p-value
		Sample average		Tuz gölü			
		Average	Standard Deviation	Average	Standard Deviation		
pH	-	6.62	0.38	7.71	0.00	-0.744	0.000
Electricity_conductivity	µs/cm	28250.00	63219.85	100000.00	0.00	-0.744	0.000
Salinity	%o	96.83	37.53	86.00	0.00	-0.744	0.317
Dissolved_solids	mg/L	55020.92	17392.97	50000.00	0.00	-0.744	0.317
Suspended_materials	mg/L	10.00	.00	105.90	0.00	-0.744	0.000
Sulphate	mg/L	2320.92	355.15	9670.00	0.00	-0.744	0.000
Chloride	mg/L	169399.33	54128.26	194139.00	0.00	-0.744	0.021
Alkalinity	$CaCo_3/L$	110.95	16.65	159.60	0.00	-0.744	0.000
Nitrate	mg/L	0.76	0.50	00.66	0.00	-0.744	0.083
Nitrite	mg/L	0.02	0.01	0.07	0.00	-0.744	0.000
Ammonium_nitrogen	mg/L	0.06	0.04	0.97	0.00	-0.744	0.000
Sodium	mg/L	106015.25	10895.21	139581.00	0.00	-0.744	0.000
Magnesium	mg/L	38.60	20.14	4832.00	0.00	-0.744	0.000
Calcium	mg/L	1059.67	206.98	672.49	0.00	-0.744	0.000
Oil_grease	mg/L	**10.00**	**-**	**.**	**.**		

In 2016, salinity, dissolved solids and nitrate values were similar in the sample and Tuz gölü averages and the differences were not statistically significant since $p>0.05$. Calcium value was statistically significantly higher in sample measurements. The values of all other measurement values for all months of 2016 were statistically significantly higher for Tuz Gölü since $p<0.05$.

For 2017, the differences between the measured values and Tuz Gölü values and the results of the difference analysis are given in Table 4.

In 2017, nitrate, nitrite and calcium levels were statistically significantly higher in the measurements of the samples since p<0.05. However, pH, sulphate, chloride, alkaline, ammonium nitrogen, sodium and magnesium averages were higher in Tuz Gölü since p<0.05. The mean values of electrical conductivity, salinity, dissolved solids and suspended matter were not statistically significant since p>0.05.

Table 4. Differences and difference analysis results between the measured values and Tuz gölü values for 2017

Parameters	Unit	Sampling				Test Value	p-value
		Sample average		Tuz gölü			
		Average	Standard Deviation	Average	Standard Deviation		
pH	-	6.80	0.46	7.71	0.00	12.000	0.000
Electricity_conductivity	µs/cm	100000.00	0.00	100000.00	0.00	72.000	1.000
Salinity	%o	86.00	0.00	86.00	0.00	72.000	1.000
Dissolved_solids	mg/L	50000.00	0.00	50000.00	0.00	72.000	1.000
Suspended_materials	mg/L	177.16	204.39	105.90	0.00	72.000	1.000
Sulphate	mg/L	3056.17	978.24	9670.00	0.00	0.000	0.000
Chloride	mg/L	159191.92	18441.95	194139.00	0.00	0.000	0.000
Alkalinity	$CaCo_3$/L	115.52	16.14	159.60	0.00	0.000	0.000
Nitrate	mg/L	1.71	0.87	0.66	0.00	22.000	0.004
Nitrite	mg/L	0.10	0.18	0.07	0.00	36.000	0.026
Ammonium_nitrogen	mg/L	0.09	.010	0.97	0.00	0.000	0.000
Sodium	mg/L	82707.35	44413.94	139581.00	0.00	12.000	0.000
Magnesium	mg/L	37.59	22.66	4832.00	0.00	0.000	0.000
Calcium	mg/L	1391.08	658.10	672.49	0.00	0.000	0.000
Oil_grease	mg/L	10.00	0.00	.	.		

For 2018, the differences between the measured values and Tuz gölü values and the results of the difference analysis are given in Table 5.

Table 5. Differences and difference analysis results between measured values and Tuz gölü values for 2018

Parameters	Unit	Sampling				Test Value	p-value
		Sample average		Tuz gölü			
		Average	Standard Deviation	Average	Standard Deviation		
pH	-	6.35	0.60	7.71	0.00	0.000	0.000
Electricity_conductivity	µs/cm	10000.00	0.00	100000.00	0.00	0.000	0.000
Salinity	%o	86.00	0.00	86.00	0.00	72.000	1.000
Dissolved_solids	mg/L	50000.00	.000	50000.00	0.00	72.000	1.000
Suspended_materials	mg/L	110.86	109.04	105.90	0.00	48.000	0.139
Sulphate	mg/L	2777.00	254.03	9670.00	0.00	0.000	0.000
Chloride	mg/L	174329.67	17156.10	194139.00	0.00	12.000	0.000
Alkalinity	$CaCo_3$/L	127.93	76.77	159.60	0.00	12.000	0.000
Nitrate	mg/L	1.01	0.62	0.66	0.00	72.000	1.000
Nitrite	mg/L	0.03	0.01	0.07	0.00	0.000	0.000
Ammonium_nitrogen	mg/L	0.17	0.17	0.97	0.00	0.000	0.000
Sodium	mg/L	103092.75	12079.90	139581.00	0.00	0.000	0.000
Magnesium	mg/L	30.18	2.04	4832.00	0.00	0.000	0.000
Calcium	mg/L	1269.22	144.71	672.49	0.00	0.000	0.000
Oil_grease	mg/L	10.00	0.00	.	0.00		

In 2018, pH, electrical conductivity, sulphate, chloride, alkaline, nitrite, ammonium nitrogen, sodium and magnesium averages are higher for Tuz Gölü and the differences were statistically significant since p<0.05. Calcium averages were higher in the samples, and the differences were statistically significant since p<0.05. The difference in salinity, dissolved solids, suspended solids and nitrate averages between the samples and Tuz Gölü was not statistically significant since it is >0.05. For 2019, the differences between the measured values and Tuz gölü values and the results of the difference analysis are given in Table 6.

Table 6. Differences and difference analysis results between measured values and Tuz gölü values for 2019

Parameters	Unit	Sampling				Test Value	p-value
		Sample average		Tuz gölü			
		Average	Standard Deviation	Average	Standard Deviation		
pH	-	5.92	0.35	7.71	0.00	0.000	0.000
Electricity_conductivity	µs/cm	10000.00	0.00	100000.00	0.00	0.000	0.000
Salinity	%o	86.00	0.00	86.00	0.00	72.000	1.000
Dissolved_solids	mg/L	50000.00	0.00	50000.00	0.00	72.000	1.000
Suspended_materials	mg/L	74.13	55.53	105.90	0.00	48.000	0.139
Sulphate	mg/L	3021.58	268.75	9670.00	0.00	0.000	0.000
Chloride	mg/L	180610.25	8001.07	194139.00	0.00	12.000	0.000
Alkalinity	$CaCo_3/L$	98.90	21.80	159.60	0.00	0.000	0.000
Nitrate	mg/L	0.90	0.30	0.66	0.00	48.000	0.138
Nitrite	mg/L	0.07	.12	0.07	0.00	24.000	0.003
Ammonium_nitrogen	mg/L	.18	.14	0.97	0.00	0.000	0.000
Sodium	mg/L	105892.92	39763.58	139581.00	0.00	24.000	0.003
Magnesium	mg/L	35.14	8.37	4832.00	0.00	0.000	0.000
Calcium	mg/L	1384.08	348.33	672.49	0.00	0.000	0.000
Oil_grease	mg/L	10.00	0.00	.	0.00		

In 2019, pH, electrical conductivity, sulphate, chloride, alkaline, nitrite, ammonium nitrogen, sodium and magnesium averages are higher for Tuz Gölü and the differences were statistically significant since p<0.05. Calcium averages were statistically significantly higher in the samples (p<0.05). The difference in salinity, dissolved solids, suspended solids and nitrate averages between the samples and Tuz Gölü was not statistically significant since p>0.05. For 2020, the differences between the measured values and Tuz gölü values and the results of the difference analysis are given in Table 7.

Tablo 7. Differences and difference analysis results between measured values and Tuz gölü values for 2020

Parameters	Unit	Sampling				Test Value	p-value
		Sample average		Tuz gölü			
		Average	Standard Deviation	Average	Standard Deviation		
pH	-	6.39	0.51	7.71	0.00	0.000	0.000
Electricity_conductivity	µs/cm	100000.00	0.00	100000.00	0.00	72.000	1.000
Salinity	%o	86.00	0.00	86.00	0.00	72.000	1.000
Dissolved_solids	mg/L	50000.00	0.00	50000.00	0.00	66.000	0.317
Suspended_materials	mg/L	85.67	66.18	105.90	0.00	72.000	1.000
Sulphate	mg/L	2252.42	772.55	9670.00	0.00	0.000	0.000
Chloride	mg/L	164273.67	21248.02	194139.00	0.00	0.000	0.000
Alkalinity	$CaCo_3/L$	119.95	20.26	159.60	0.00	0.000	0.000
Nitrate	mg/L	1.43	0.47	.66	0.00	0.000	0.000
Nitrite	mg/L	0.03	0.03	.07	0.00	12.000	0.000
Ammonium_nitrogen	mg/L	0.26	0.37	.97	0.00	12.000	0.000
Sodium	mg/L	115965.83	24570.34	139581.00	0.00	24.000	0.003
Magnesium	mg/L	43.10	17.94	4832.00	0.00	0.000	0.000
Calcium	mg/L	1361.92	399.23	672.49	0.00	0.000	0.000
Oil_grease	mg/L	10.00	0.00	.	0.00		

In 2020, the averages of nitrate and calcium were statistically significantly higher in the samples since p<0.05. The differences in electrical conductivity, salinity, dissolved solids, suspended solids and nitrate levels between the samples and Tuz Gölü values were not statistically significant since p>0.05. pH, sulphate, chloride, alkaline, nitrite, ammonium nitrogen, sodium and magnesium values were statistically significantly higher in Tuz Gölü since p<0.05 (p<0.05).

For the year 2021, the differences between the measured values and the Tuz Gölü values and the results of the difference analysis are given in Table 8.

Table 8. Differences and difference analysis results between measured values and Tuz gölü values for 2021

Parameters	Unit	Sampling				Test Value	p-value
		Sample average		Tuz gölü			
		Average	Standard Deviation	Average	Standard Deviation		
pH	-	6.13	0 .43	7.71	0.00	0.000	0.014
Electricity_conductivity	µs/cm	10000.00	0.00	100000.00	0.00	0.000	0.008
Salinity	%o	86.00	0.00	86.00	0.00	8.000	1.000
Dissolved_solids	mg/L	50000.00	0.00	50000.00	0.00	8.000	1.000
Suspended_materials	mg/L	35.98	13.91	105.90	0.00	0.000	0.014
Sulphate	mg/L	3158.50	223.62	9670.00	0.00	0.000	0.014
Chloride	mg/L	183467.75	5218.87	194139.00	0.00	0.000	0.014
Alkalinity	$CaCo_3$/L	119.20	6.18	159.60	0.00	0.000	0.014
Nitrate	mg/L	**1.17**	**0.05**	0.66	0.00	0.000	0.014
Nitrite	mg/L	0.01	0.00	0.07	0.00	0.000	0.008
Ammonium_nitrogen	mg/L	0.12	0.02	0.97	0.00	0.000	0.014
Sodium	mg/L	124468.25	13141.53	139581.00	0.00	0.000	0.014
Magnesium	mg/L	42.23	14.02	4832.00	0.00	0.000	0.014
Calcium	mg/L	**1390.50**	**170.91**	672.49	0.00	0.000	0.014
Oil_grease	mg/L	10.00	0.00	.	0.00		

In 2021, nitrate and calcium averages were statistically significantly higher in the samples since $p<0.05$. The differences in salinity and dissolved solids levels between the samples and Tuz gölü values were not statistically significant since $p>0.05$. Suspended matter, pH, sulphate, chloride, alkaline, nitrite, ammonium nitrogen, sodium and magnesium values were statistically significantly higher in Tuz Gölü since $p<0.05$. For the year 2022, the differences between the measured values and Tuz gölü values and the results of the difference analysis are given in Table 9.

Table 9. Differences and difference analysis results between measured values and Tuz gölü values for the year 2022

Parameters	Unit	Sampling				Test Value	p-value
		Sample average		Tuz gölü			
		Average	Standard Deviation	Average	Standard Deviation		
pH	-	6.82	1.06	7.71	0.00	0.000	0.002
Electricity_conductivity	µs/cm	141300.00	65593.23	100000.00	0.00	9.000	0.108
Salinity	%o	127.43	66.01	86.00	0.00	9.000	0.108
Dissolved_solids	mg/L	69040.33	36309.91	50000.00	0.00	12.000	0.253
Suspended_materials	mg/L	168.57	150.48	105.90	0.00	6.000	0.040
Sulphate	mg/L	3345.83	832.11	9670.00	0.00	0.000	0.002
Chloride	mg/L	106833.00	32360.32	194139.00	0.00	0.000	0.002
Alkalinity	$CaCo_3$/L	123.27	11.87	159.60	0.00	0.000	0.002
Nitrate	mg/L	2.57	1.39	0.66	0.00	6.000	0.040
Nitrite	mg/L	0.21	0.12	0.07	0.00	6.000	0.040
Ammonium_nitrogen	mg/L	0.14	0.14	0.97	0.00	0.000	0.002
Sodium	mg/L	57785.22	17696.22	139581.00	0.00	0.000	0.002
Magnesium	mg/L	32.02	7.98	4832.00	0.00	0.000	0.002
Calcium	mg/L	1223.32	252.23	672.49	0.00	0.000	0.002
Oil_grease	mg/L	10.00	0.00	.	0.00		

In 2022, suspended matter, nitrate and nitrite levels and calcium levels were statistically significantly higher in the samples than in Tuz Gölü since $p<0.05$. The differences between the sample and Tuz Gölü averages for electrical conductivity, salinity, dissolved solids were not statistically significant since $p>0.05$. pH, sulphate, chloride, alkalinity, ammonium nitrogen, sodium and magnesium averages were statistically significantly higher in Tuz Gölü since $p<0.05$. For the year 2023, the differences between the measured values and Tuz Gölü values and the results of the difference analysis are given in Table 10.

Table 10. Differences and difference analysis results between measured values and Tuz gölü values for the year 2023

Parameters	Unit	Sampling				Test Value	p-value
		Sample average		Tuz gölü			
		Average	Standard Deviation	Average	Standard Deviation		
pH	-	7.26	0.31	7.71	0.00	0.000	0.005
Electricity_conductivity	μs/cm	160738.00	95992.90	100000.00	0.00	5.000	0.095
Salinity	%o	206.00	25.43	86.00	0.00	0.000	0.007
Dissolved_solids	mg/L	113422.50	11349.07	50000.00	0.00	0.000	0.007
Suspended_materials	mg/L	91.74	114.37	105.90	0.00	5.000	0.095
Sulphate	mg/L	6171.80	7828.65	9670.00	0.00	5.000	0.095
Chloride	mg/L	177065.20	68114.97	194139.00	0.00	10.000	0.577
Alkalinity	$CaCo_3$/L	130.60	15.76	159.60	0.00	0.000	0.005
Nitrate	mg/L	31.05	67.06	.66	0.00	10.000	0.577
Nitrite	mg/L	0.03	0.04	.07	0.00	5.000	0.090
Ammonium_nitrogen	mg/L	.02	0.00	.97	0.00	0.000	0.003
Sodium	mg/L	72967.20	42334.87	139581.00	0.00	0.000	0.005
Magnesium	mg/L	53.12	44.73	4832.00	0.00	0.000	0.005
Calcium	mg/L	910.64	527.73	672.49	0.00	5.000	0.095
Oil_grease	mg/L	10.00	0.00	.	.		

In 2023, salinity, dissolved solids averages were statistically significantly higher since p<0,05. The differences between the sample and Tuz Gölü averages for electrical conductivity, suspended solids, sulphate, chloride were not statistically significant since p>0.05. pH, alkalinity, ammonium nitrogen, sodium and magnesium averages were statistically significantly higher in Tuz Gölü since p<0.05. The results of the "Spearman's rho correlation analysis" performed to analyse the seasonal dependence of the measurement values for the samples are given in Table 11.

Table 11. Results of Spearman's rho correlation analysis to analyze the seasonal dependence of measurement values for the samples

Parameter	Unit	r	P
pH	-	-0.190	0.078
Electricity_conductivity	μs/cm	0.004	0.970
Salinity	%o	-0.071	0.516
Dissolved_solids	mg/L	-0.049	0.656
Suspended_materials	mg/L	-0.040	0.710
Sulphate	mg/L	0.173	0.109
Chloride	mg/L	0.134	0.217
Alkalinity	$CaCo_3$/L	-0.294^{**}	0.006
Nitrate	mg/L	-0.012	0.914
Nitrite	mg/L	0.200	0.063
Ammonium_nitrogen	mg/L	0.191	0.077
Sodium	mg/L	0.057	0.599
Magnesium	mg/L	-0.058	0.595
Calcium	mg/L	0.087	0.425

According to the results of Spearman's rho correlation analysis, there was a negative correlation between alkalinity level and month (r=-0.294; p<0.01). Therefore. as the month progressed, alkalinity decreased significantly. All other measurement parameters were not time-dependent for the samples and did not differ historically (p>0.05). For the years 2022 and 2023, the analysis results of Magnesium, Iron, Total Chromium, Sodium, Lithium, Aluminium, Mangenesis, Copper, Zinc, Boron, Cobalt, Nickel, Arsenic, Cadmium, Lead, Lead, Mercury, which can be considered pollution parameters although they are not heavy metals and heavy metals are given in Tables 12, 13 and 14.

Table 12. Analysis results for 2022

Parameter	Unit	April	May	June	July	November	December	*Tuz Gölü Results
Magnesium	mg/L	32.7	33.504	33.93	44.1	19.7	28.2	**4832**
Iron	mg/L	0.322	0.447	<0.005	<0.005	<0.005	0.8213	**1.026**
Chromium	mg/L	<0.001	<0.001	<0.001	0.002	<0.001	0.0028	**0.069**
Sodium	mg/L	38734	47490.7	69586.6	85973	45170	59757	**139581**
Lithium	mg/L	0.028	0.015	0.04432	<0.001	<0.001	<0.001	**39.13**
Aluminium	mg/L	0.631	<0.02	<0.02	<0.02	<0.02	0.1644	**0.849**
Manganese	mg/L	0.067	0.095	<0.0005	0.087	0.0109	0.0541	**0.109**
Copper	mg/L	<0.001	0.021	<0.001	0.017	0.0073	0.4267	**0.145**
Zinc	mg/L	0.04	0.056	<0.001	0.155	0.0643	0.4022	**0.353**
Boron	mg/L	<0.02	0.729	<0.02	0.642	1.18	<0.02	**69.78**
Cobalt	mg/L	<0.0005	<0.0005	<0.0005	0.002	<0.0005	<0.0005	**0.0018**
Nickel	mg/L	0.007	<0.005	<0.005	0.005	0.0052	<0.005	**0.088**
Arsenic	mg/L	0.013	0.012	<0.0005	0.014	0.0031	0.0088	**0.577**
Cadmium	mg/L	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	**<0.0005**
Lead	mg/L	0.002	<0.0005	<0.0005	<0.0005	<0.0005	0.0055	**0.0072**
Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	**0.0084**

Table 13. Analysis results for 2023 (First 6 months)

Parameter	Unit	January	February	March	April	May	June	*Tuz Gölü Results
Magnesium	mg/L	33.9	36.5	133	33	29.2	4170.1	**4832**
Iron	mg/L	0.4465	0.4475	0.0436	<0.005	<0.005	0.0069	**1.026**
Chromium	mg/L	<0.001	<0.001	0.0020	<0.001	<0.001	0.003	**0.069**
Sodium	mg/L	75585	83486	309	102079	103377	43897	**139581**
Lithium	mg/L	0.0561	0.0390	0.1959	<0.001	0.0898	21.5310	**39.13**
Aluminium	mg/L	<0.02	<0.02	0.0354	<0.02	<0.02	<0.02	**0.849**
Manganese	mg/L	0.0347	0.0335	0.0058	0.0227	0.04	0.004	**0.109**
Copper	mg/L	<0.001	<0.001	0.0713	<0.001	<0.001	0.01	**0.145**
Zinc	mg/L	0.0765	<0.001	0.1970	0.1227	<0.001	0.01	**0.353**
Boron	mg/L	1.77	3.60	1.58	0.53	4.5314	48.5212	**69.78**
Cobalt	mg/L	<0.0005	<0.0005	0.0006	<0.0005	<0.0005	<0.0005	**0.0018**
Nickel	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	**0.088**
Arsenic	mg/L	0.0137	0.0186	0.1423	0.0118	0.0108	0.0225	**0.577**
Cadmium	mg/L	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	**<0.0005**
Lead	mg/L	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	**0.0072**
Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	**0.0084**

Table 14. Analysis results for 2023 (Second 6 months)

Parametre	Unit	July	August	September	October	November	December	*Tuz Gölü Results
Magnesium	mg/L	<0.05	27	37	38.33	75.61728	31.55	**4832**
Iron	mg/L	<0.005	<0.005	0.02	<0.005	0.0532	0.2	**1.026**
Chromium	mg/L	<0.001	<0.001	0.02	<0.001	<0.001	0	**0.069**
Sodium	mg/L	13095	96052	86848	112935	271245.675	158310.0	**139581**
Lithium	mg/L	<0.001	0.04	0.001	0.0695	0.15741	0.04	**39.13**
Aluminium	mg/L	<0.02	<0.02	<0.02	<0.005	<0.02	0.1	**0.849**
Manganese	mg/L	0.01	<0.0005	0.19	<0.0005	0.05831	0.0	**0.109**
Copper	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0	**0.145**
Zinc	mg/L	<0.001	<0.001	0.1	<0.001	<0.001	1.55	**0.353**
Boron	mg/L	<0.02	3.51	<0.02	<0.02	4.33867	11.4	**69.78**
Cobalt	mg/L	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	**0.0018**
Nickel	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	**0.088**
Arsenic	mg/L	<0.0005	0.0007	0.0154	<0.0005	0.03406	0	**0.577**
Cadmium	mg/L	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	**<0.0005**
Lead	mg/L	<0.0005	<0.0005	<0.0005	<0.0005	0.00275	0.0	**0.0072**
Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	**0.0084**

5. RESULT AND DISCUSSION

To determine the environmental impacts of the Tuz gölü Underground Natural Gas Storage Project on Tuz gölü, which constituted the purpose of this study. the results of the analyses of the samples taken for control purposes by the institution within the scope of this project were statistically evaluated, and it was tried to be understood whether the relevant discharge had a statistically significant effect. In this context, as a result of the evaluation, it was understood that the cumulative data in the sum of the years were close to the Tuz gölü and below the Tuz gölü values. According to the results of the analyses, dissolved solids and calcium values of the sample averages are statistically significantly higher than the average of Tuz Gölü since $p<0.05$. However, pH, electrical conductivity, suspended matter, alkalinity, sulphate, chloride, nitrate, nitrite, ammonium nitrogen, sodium and magnesium averages are statistically significantly lower than the average values of Tuz Gölü since $p<0,05$. According to these results, it was seen that the levels of pollutants were below the average of Tuz Gölü and this difference was significant. This result supports the interpretation that Tuz gölü, which was evaluated by core analysis during the EIA phase of the project, and the formation used in storage come from the same source. In addition, when the heavy metal and pollutant parameters of Magnesium, Iron, Total Chromium, Sodium, Lithium, Aluminium, Mangenesis, Copper, Zinc, Boron, Cobalt, Nickel, Arsenic, Cadmium, Lead, Mercury for 2022 and 2023 were examined, it was seen that these values were below the current concentrations in Tuz Gölü. In the process of creating natural gas storage caverns, only fresh water was used for dissolving. Thus. there was no chemical interference. In addition, the discharged water causes an increase in the water level of Tuz gölü and had a positive effect on the lake, which is getting drier day by day. The amount of water used for the formation of each cavern is given in Table 15.

Table 15. Amount of water required for the formation of a cavern

Phase	Amount of Water Required for the Formation of a Cavern		
	Hourly	Daily	Annual
Solving Phase	280 m^3	6.720 m^3	2.419.200 m^3

Considering that the formation of a cavern takes approximately 1000 days, there was a significant amount of discharge. The protection of endemic species in Tuz Gölü due to the increase in water level also contributes positively to the protection of bird species that spend their incubation period in the region. Following the realisation of the water discharge, 9.564 flamingo chicks in 2016. 11.079 chicks in 2017, 12.746 chicks in 2018, and 20.385 flamingo chicks in 2019 were detected in the Tuz Gölü Special Environmental Protection Area during the investigations carried out in the "Research. Protection and Monitoring of Flamingo Populations Project" carried out by the Ministry of Environment and Urbanisation. [17]. In this study, it is understood that the parameters of the discharged water are appropriate. but suggestions are given below not to pose a problem in the future.

- There should not be any different discharges to the water stored in the brine ponds.
- The insoluble and precipitated substances in the brine kept in the brine pools should be cleaned at regular intervals for disposal/recovery, In this way, solid material transport to Tuz gölü should be prevented.
- To realise the discharge in a controlled manner, monthly samples should continue to be taken and evaluated.

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