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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Investigation of Water Quality of the Karasu River in Bilecik Province in terms of Agricultural Irrigation

Bilecik İli Karasu Irmağı Su Kalitesinin Tarımsal Sulamalar Açısından İncelenmesi

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Abstract

Together with increasing people's need for water, water needs to be monitored due to the pressure created by factors such as drought and pollution. In this study, water quality was monitored by determining 10 points on the Karasu River in Bilecik Province and it was aimed to examine the seasonal change in water quality. pH, EC, Na, K, Ca, Mg, CO_3, HCO_3, Cl, B, SO_4, Sodium Adsorption Rate (SAR), Residual Sodium Carbonate (RSC) and %Na parameters were determined in water. And then using these parameters, quality classes were determined with the help of water quality classification systems developed by scientists such as Schofield, Wilcox, Thorne, Doneen and Soifer. The study were temporally diveded into 4 periods. They are period 1, period 2 (Spring), period 3 (Summer) and period 4 (Fall). After all, for the period 3, heavy metal pollution, especially Al, attracts attention. Except for the period 2 of point 7 and period 4 of point 9, the class of all periods and points in terms of sulphate was "Very good (class 1)". According to Schofield (1933 and 1935) systems, point 7 is in particularly bad situation in terms of EC. According to Wilcox (1948), point 7 is not suitable for irrigation in the period 2. At point 7, water pollution in period 2 has been identified as common to most classification systems. According to Christiansen et al. (1977), there is intense pollution in terms of EC and Na_2CO_3 parameters. According to Soifer (1987), point 2 is the cleanest point. As a result, Karasu river is not suitable for irrigation in terms of Al and B. It was understood that heavy metal pollution did not cause much of a problem in non-industrialized cities such as Bilecik. Besides, it was understood that the most common element among heavy metals was Pb in Karasu River. The SAR and RSC values of all periods, seasons and points were classified as "Very Good-Safe (C1S1)".

Keywords: Agricultural water quality, Water quality index, Water quality classification systems, Sakarya river, Karasu stream

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Öz

İnsanların suya olan ihtiyaçlarının artmasına ek olarak, kuraklık ve kirlilik gibi etmenlerin yaratacağı baskı sebebiyle suların izlenmesi gerekmektedir. Bu çalışmada; Bilecik ili Karasu ırmağı üzerinde 10 nokta belirlenerek su kalitesi izlenmiş ve mevsimsel olarak su kalitesindeki değişimin incelenmesi amaçlanmıştır. Sudaki; pH, EC, Na, K, Ca, Mg, CO_3, HCO_3, Cl, B, SO_4, Sodyum Adsorpsiyon Oranı (SAR), Kalıntı sodyum karbonat (RSC) ve %Na parametreleri belirlenmiştir. Daha sonra bu parametreler kullanılarak; Schofield, Wilcox, Thorne, Doneen ve Soifer gibi bilim insanlarının geliştirdiği, su kalitesi sınıflandırma sistemleri yardımıyla kalite sınıfları belirlenmiştir. Çalışma, zamansal olarak; 1. dönem, 2. dönem (İlkbahar), 3. dönem (Yaz) ve 4. dönem (Sonbahar) şeklinde 4 döneme ayrılmıştır. Sonuçta; 3. dönem için; Al başta olmak üzere ağır metal kirliliği dikkate çekmektedir. 2. dönemin 7 nolu noktası ve 4. dönemim 9 nolu noktaları haricinde, tüm dönem ve noktalar sülfat açısından "Çok iyi (1. sınıf)" dir. Schofield (1933 ve 1935) sistemlerine göre; 7 nolu nokta, özellikle EC açısından kötü durumdadır. Wilcox (1948)'a göre; 7 nolu nokta, 2. dönemde sulama açısından uygun değildir. 7 nolu noktada, 2. dönemdeki su kirliliği, çoğu sınıflandırma sisteminde ortak olarak tespit edilmiştir. Christiansen ve ark. (1977)'na göre, EC ve Na_2CO_3 parametreleri açısından yoğun bir kirlilik yaşanmaktadır. Soifer (1987)'a göre, 2 nolu nokta en temiz noktadır. Sonuç olarak; Karasu ırmağı, Al ve B açısından sulamaya uygun değildir. Bilecik gibi sanayileşmemiş şehirlerde, ağır metal kirliliğinin çok fazla sorun yaratmadığı anlaşılmıştır. Ayrıca; Karasu Irmağı'ndaki ağır metaller arasında en yaygın bulunan elementin Pb olduğu anlaşılmıştır. Tüm dönem, mevsim ve noktalara ait SAR ve RSC değerleri "Çok İyi-Güvenli (C1S1)" sınıfında yer almaktadır.

Anahtar Kelimeler: Tarımsal su kalitesi, Su kalite indeksi, Su kalitesi sınıflandırma sistemleri, Sakarya nehri, Karasu ırmağı

1. Introduction

Greenhouse gases and pollutants released into the atmosphere by industrializing countries such as Turkey both cause global warming and indirectly pollute water resources (Alaboz et al., 2020). As climate change is excessively experienced on the Mediterrenean watershed, water resources must be managed wisely. Especially in drought country, management of water quality is very essential topic (Gençoğlan et al., 2023).

Nowadays, effective usage and protection of land and water resources and sustainable agriculture are among the priority issues. Owing to the increasing need for water and the pressure on water resources due to factors such as drought and pollution, it becomes necessary to protect water in terms of both quantity and quality. In this context, water monitoring is the primary issue. It forms the basis for the management studies to be implemented. The quality of irrigation water has a significant impact on both crop yield and soil properties. Due to pollution in irrigation water, high osmotic pressures occur in the plant sap and the plant cannot use the available water, which is called physiological drought. The situation means that the plant suffers from a deficiency of both water and plant nutrients. Another side effect is the effect of phytotoxic compounds present in the water on the plant. It is known that this situation is more effective especially during the germination and early development periods. The second effect of irrigation water on plant development is due to its negative effects on the soil. The relationship between water quality and soil causes changes in some physical properties of the soil, such as infiltration rate, soil structure, air and water permeability.

The selection of the irrigation method and the irrigation planning to be applied vary depending on the water quality. Especially in surface irrigation methods where water is applied in larger amounts, the usage of problematic water accelerates the negative processes. In addition, it is possible to consider the need for wash water and carry out reclamation works in order to prevent or eliminate the negative effects that may occur in the soil depending on the water quality, by monitoring the water quality. In general, cation concentrations in freshwater are expected to be Ca>Mg>Na>K. Besides, sulphate deficiency prevents algae growth. Biological Oxygen Demand (BOD) is the amount of oxygen required to decompose organic substances under oxygenated conditions. Chemical Oxygen Demand (COD) shows the amount of oxygen required for the oxidation of all substances in water. For this reason, COD is actually more inclusive. If COD is bigger than 25 mg l^{-1}, it means that the water is polluted (Tepe and Kutlu, 2019).

Kapdı and Aşık (2021) took water samples in Uşak Güllübağ pond in March-May-July and performed physico-chemical analysis. According to SAR, MAR (Magnesium Adsorption Rate), Kelley Index, Permeability Index, Potential Salinity, %Na and EC results, pond water was classified as suitable for irrigation. After all, it was determined that the lake water was of 2nd class quality in terms of Cl and boron, and 1st class quality in terms of sulphate. In terms of irrigation water indices, the results varied in the following ranges: %Na: 52.8-54.6, SAR: 3.1-3.5, MAR: 35.6-37.1, Kelley Index: 0.94-1, Permeability Index: 72.5-75, Potential Salinity: 4.4-5.72 meq l^{-1}. Heavy metal pollution could not be detected in the waters. Karademir et al. (2020) examined the quality of water consumed by farm animals in the Iğdır Aras River. In this context, heavy metals such as Cu, Zn, Mn, Fe and macro ions such as Na, K, Ca, Mg were analyzed. After all, they found lower quality water in Tuzluca district compared to other districts. In general, it has been determined that the water resources in Iğdır are suitable for the usage of farm animals. Ağca and Doğan (2020) determined ions, SAR, MAR, permanent bicarbonate and total hardness values, which are important for agricultural water quality, from 8 points in the Asi River. After all, the order of the amount of cations in the river is Mg>Na>Ca>K and the order of the anions is SO_4>HCO_3>Cl>CO_3. Water quality class of the river is C3S1. In terms of salinity, it is in the "Very salty water" class. Moreover, a strong negative correlation was detected between RSC and Mg (R^2: -0.91). In this situation, the River water should be used carefully for irrigation of crops, which sensitive to Mg deficiency, such as sugar beet, citrus, vineyard, tomato, onion and potato. Topçu and Taş (2020) analyzed the ions that are important for agricultural water quality in the water of 20 wells in the Çanakkale Biga plain and determined that 11 wells had Class 2 water and 9 wells had Class 1 water. They said that the EC values of the wells especially were high around Koruoba and Örtülüce. Tepe and Kutlu (2019) analyzed water samples from depths of 0-4-8 m at 5 stations in the Karkamış Dam Lake in Gaziantep in 2015. Some quality parameters for these 3 depths are respectively (average temperature: 9.5 °C): For pH: 8.5-9-7.8, for EC: 251-332-412 µS cm^{-1}, for Dissolved Oxygen: 9-10-12 mg l^{-1}, for TP: 0.007-0.016-0.026 mg l^{-1}, for TN: 0.72-1.15-1.70 mg l^{-1}. After all, they determined that the lake water had high quality (1st class). Diri (2018) analyzed the water received from 17 points in the Konya watershed and 3 points in the Sakarya watershed.

As a result, while the waters at 3 points were found to be suitable for irrigation, it was understood that the other points were not suitable for irrigation. In addition, although they were suitable in terms of EC and Cl, it was understood that they were not suitable in terms of B and Na. Kar and Leblebici (2020) obtained seasonally 125 samples from 5 points in the Yamula Dam lake in Kayseri and performed a detailed analysis of water quality. After all, they determined that TP, TN, SO_4, Cl, K, Na and pH are effective parameters in evaluating the quality of this lake. Dündar (2008) carried out detailed analysis of many parameters in water and sediment samples in the Lower Sakarya River in 2007. As a result, it was determined that the pollution in the watershed was caused by fertilizers and pesticides in settlements and agricultural areas. Akkan and Mutlu (2022) examined the chromium, manganese, lead, iron, cobalt, nickel, copper, zinc, aluminium and cadmium values in the Artvin Çoruh River watershed. As a result, using the water quality index, they determined that the water quality of the river was in the poor class. After all, they stated that the river water had a high metal load. Osmanoğlu and Özalp (2023) investigated the water quality of Artvin Murgul stream. For this purpose, parameters such as pH, EC, zinc (Zn), arsenic (As), cadmium (Cd), copper (Cu), iron (Fe) and lead (Pb) were examined monthly at 12 points throughout 1 year. As a result, it was determined that heavy metal concentrations were very high at the exit of the mine area.

In this context, monitoring the water quality in the Karasu River in Bilecik Province, it is primarily important in terms of identifying problems and taking precautions against pollution. In addition, the purpose of the study is to select the irrigation method to be applied depending on the existing water quality, to prepare and manage irrigation projects, and to obtain the necessary data for soil reclamation studies.

2. Materials and Methods

2.1. Material (Research area)

The study was carried out on the Karasu river, which is one of the water resources of Bilecik province. The river originates from Bozüyük, includes Dikilitaş, Sorgun, Selöz, Hamsu and Bekdemir streams and flows into the Sakarya River in Vezirhan. Its length is 65 km and its annual average flow rate is 1.4 $m^3 s^{-1}$. In order to monitor water quality, 10 points were selected between the Bozüyük district, which is close to the birth point of the river, and the point where it flows into the Sakarya River. During determining these points, the joining points of the streams and other discharge points were taken into consideration. Near point 3, there is a beer factory. Near point 5, Karasu River flows into the Sorgun River. Near point 5 and 6, there is Bilecik City center. Near point 7, there is a wastewater treatment plant of Bilecik Municipality and the Badun stream flows into the Sorgun (Karasu) River. Point 8 is in Vezirhan Town center (*Figure 1*).

Figure 1. Water sample points

2.2. Method

The sampling process was planned to be carried out four times throughout the year, representing each season. Water samples were taken on 04.07.2022 for period 1, on 03.03.2023 for period 2, 06.07.2023 for period 3, 08.09.2023 for period 4. During determining the sampling points, water samples were taken from 6 points as a preliminary study. In analyses, 12 parameters specified in "Scope 3: Irrigation Water Analysis" in the "Establishment, Authorization and Control Circular of Soil, Plant and Irrigation Water Analysis Laboratories for Agricultural Purposes" of the Ministry of Agriculture and Forestry were taken into consideration.

Elektrical conductivity-EC (dS m^{-1}) and pH: EC was determined by EC meter device, pH was determined by pH glass electrode pH meter.

Ca and Mg (meq l^{-1}): Determined by EDTA titration (Titrimetric) method

CO_3 and HCO_3 (meq l^{-1}): Determined by sulfuric acid titration (Titrimetric) method

Cl (meq l^{-1}): Determined by silver nitrate titration (Titrimetric) method

SO_4 (meq l^{-1}): Determined by anion and cation balance calculation

Na and K (meq l^{-1}): Determined by flame photometer device.

B (mg l^{-1}): Determined by Karmen method (Spectrophotometric).

SAR and RSC: Determined by calculation.

In addition, arsenic, aluminium, iron, chromium, lead and manganese analyzes were carried out through service procurement. However, heavy metal analyzes, which were carried out through service procurement, were only carried out on samples taken during the summer months.

Terms used to express irrigation water quality are as follows (Richards, 1954; Ayyıldız, 1983):

Sodium Adsorbtion Ratio (SAR) $= \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$ (Eq. 1)

Residual sodium carbonate (RSC)= $(CO_3 + HCO_3) - (Ca + Mg)$ (Eq. 2)

%Na= $\frac{Na^+}{(Na^+ + K^+ + Ca^{++} + Mg^{++})} . 100$ (Eq. 3)

Effective salinity: $CaCO_3$ (calcite), $MgCO_3$ (Dolomite) and $CaSO_4$ (gypsum) salts are subtracted from the total salt concentration value, respectively. The remaining amount equals the effective salinity value.

Potential salinity: $PS = Cl + 0.5\ SO_4$ (Eq. 4)

Permeability Coefficient: PC= $(Na + (HCO_3)^{0.5}) / \sum Cation$ (Eq. 5)

The standards used for irrigation water quality are as follows (Ayers and Westcot, 1989):

1. Schofield (1933) system (EC and %Na)

2. Schofield (1935) system (EC, %Na, Cl, SO_4)

3. Wilcox and Magistad (1943) system (EC, %Na, Cl, B)

4. Wilcox (1948) graphic system (EC and %Na)

5. Thorne and Thorne (1951) graphic system (EC and %Na)

6. USA Salinity Laboratory (1954) classification system (EC and SAR)

7. Doneen (1959) Potential Salinity System (Cl and SO_4)

8. Doneen (1966) Permeability Indicator System (Sodium, Bicarbonate and Total cation)

9. Christiansen et al. (1977) classification system (EC, %Na, SAR, Na_2CO_3, Cl, ES (effective salinity) and B)

10. Soifer (1987) graphic system (EC and SAR)

11. "2000/60/EC Water Framework Directive" and the "Surface Water Quality Regulation" harmonized within its scope (Official newspaper in 30th November 2012 and numbered 28483)

3. Results

3.1. Results related to period 1

Water samples taken on 04.07.2022 were analyzed on 18.07.2022 (The analysis performed on 6 samples from this period is a preliminary study). As a result, while Al, Cr, Mn, Fe could not be detected at any point, only Pb ion was found at all points in terms of heavy metals.

3.2. Results related to (Spring) period 2

On 03.03.2023, analyzes were carried out on water samples taken from 10 points. In the spring season, it was determined that K and Na results were quite low at points 1 and 2. In the spring season, while CO_3 values were close to linear, it was seen that HCO_3 results took values similar to a bell curve from upstream to downstream. Besides, SAR and pH values were determined to be suitable for usage in irrigation in the season.

3.3. Results related to (Summer) period 3

On 06.07.2023, analyzes were carried out on water samples taken from 10 points. In summer, the high Na values are noteworthy. In the summer season, the low Pb, Fe and Ar concentration values and the high Al values are noteworthy. Besides, HCO_3 values of some points are quite high. As a result, low SAR and RSC values are an indicator of good water quality in the period 3.

3.4. Results related to (Fall) period 4

On 08.09.2023, analyzes were carried out on water samples taken from 10 points. In the period 4 (Fall), the low B and CO_3 values and the high Na values are noteworthy. Compared to the previous period (Summer), the increase in RSC values in the fall season indicates a deterioration in water quality.

3.5. General Results

The high pH values in the period 4 are noteworthy. Except for the EC value of point 7 in the period 2, the period difference did not have an excessive effect on the change in EC values (*Figure 2*).

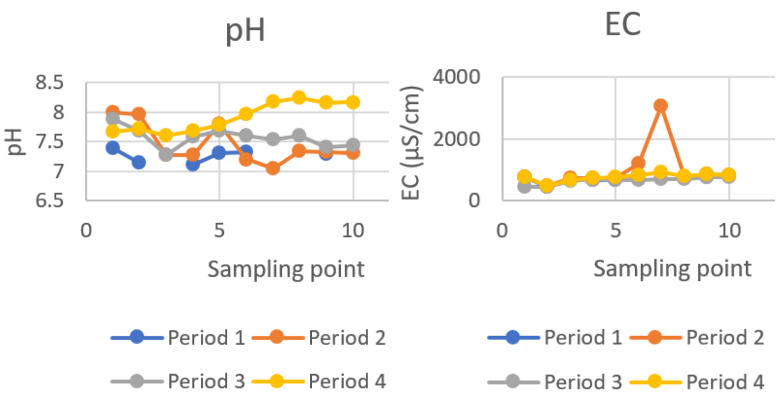

Figure 2. pH and EC results graph

The high Na values in the period 4, the low Na values in the period 1, the high K values in the period 2 and the low K values in the period 4 are noteworthy (*Figure 3*).

The high Ca values in the period 2, the low Ca values in the period 4, the high Mg values in the period 4 and the low Mg values in the period 3 are noteworthy (*Figure 4*).

It was seen that CO_3 and HCO_3 concentrations reached high values, especially in the period 2. Besides, Cl value in the point 7 is very high (*Figure 5*).

The high B values in the period 3 and the low B values in the period 4 are noteworthy. In Period 2, there was an extreme increase in the SO_4 value of point 7 (*Figure 6*).

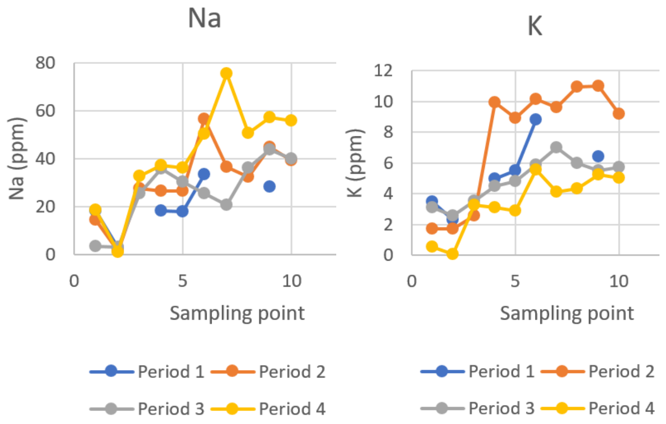

Figure 3. Na and K results graph

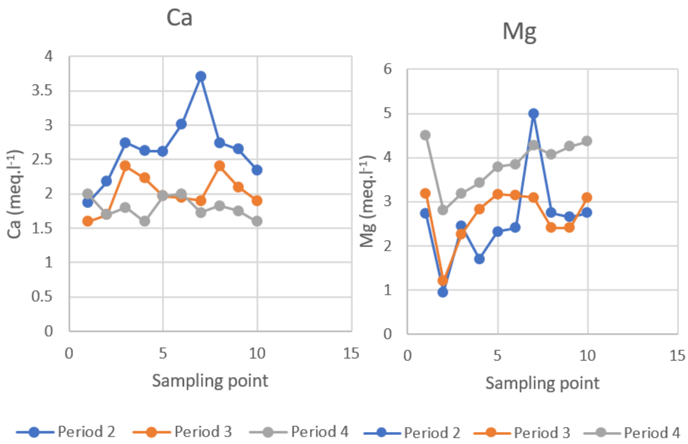

Figure 4. Ca and Mg results graph

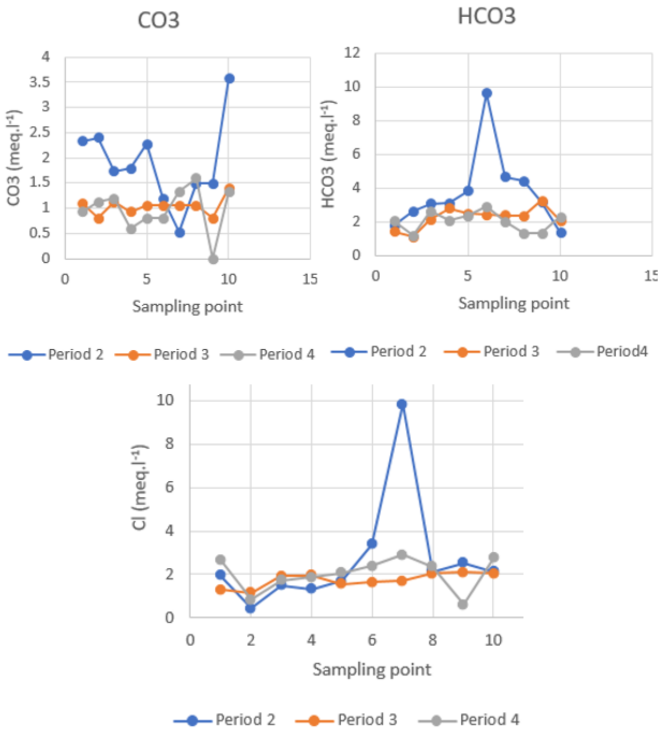

Figure 5. CO_3, HCO_3 and Cl results graph

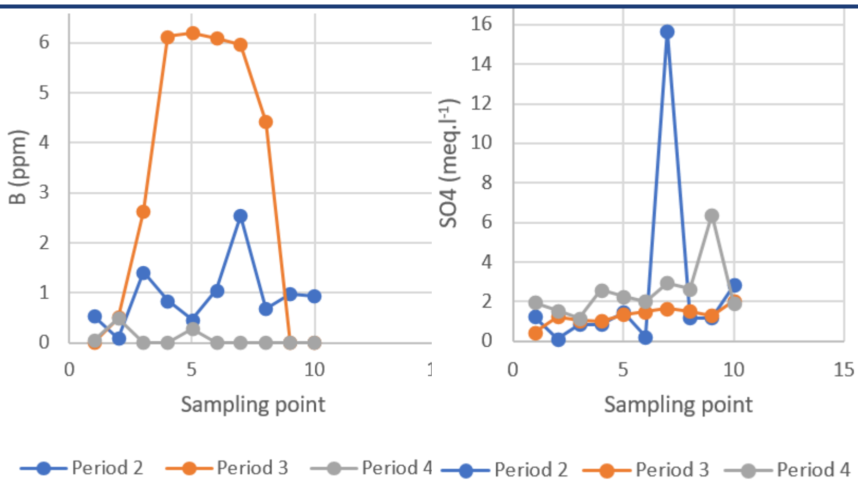

Figure 6. B and SO_4 results graph

Some of the important parameters, which determine the class of water quality are SO_4, SAR and RSC values. In terms of SO_4, except for the period 2 of point 7 and the period 4 of point 9, all SO_4 results were in the "very good (class 1)" category. Period 2 of point 7 is in class 4 (Can be used with caution) with a value of 15.67 meq l^{-1} (752.16 ppm). Besides, the period 4 of point 9 is in class 2 (good) with a value of 6.40 meq l^{-1} (307.2 ppm) (*Figure 6*).

SAR and RSC values of all periods and points were in the "Very Good-Safe (C1S1)" class. In the period 2, except for the SAR value of point 7, the low SAR and RSC values show that the Karasu River is very suitable for agricultural irrigation (*Figure 7*).

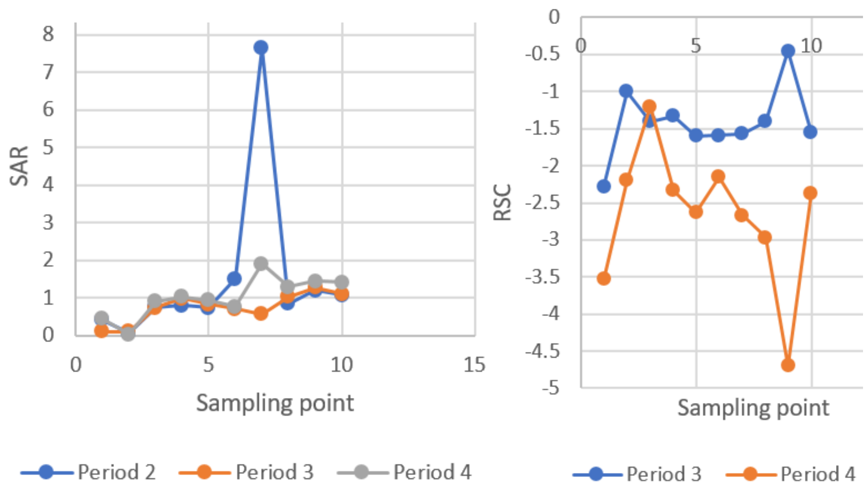

Figure 7. SAR and RSC results graph

The high Pb concentrations at points 6 and 9 are noteworthy (Figure 8).

The increased Pb concentration compared to Period 1 indicates serious Pb pollution in the River. In the period 3, especially Cr and Fe concentrations had higher values compared to other heavy metals (*Figure 9*).

In order to see the effect of temperature difference on water quality, index correlations in Summer and Fall periods were determined in this study. While the correlation (R^2: 0.29) between SAR and SO_4 was low in the summer season, the correlation (R^2: 0.72) between RSC and SO_4 was high in the fall season.

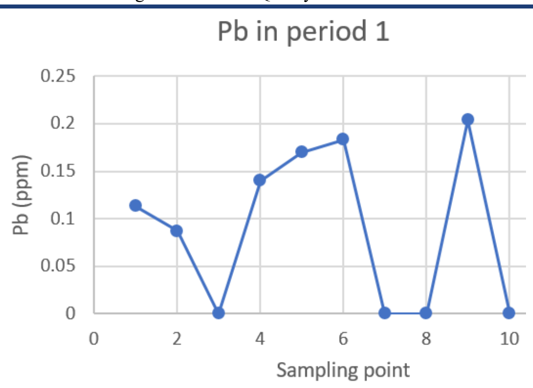

Figure 8. Pb result graph in the period 1

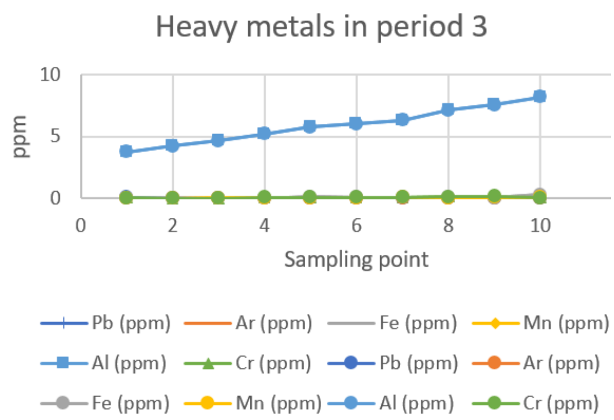

Figure 9. Heavy metals results graph in the period 3

3.6. Results related to water quality classification systems

3.6.1. Schofield (1933) system (EC and %Na)

Especially in Period 2, the pollution level of point 7 is very high. EC pollution in the period 4 is remarkable (*Table 1*).

Table 1. Results of water quality class according to Schofield (1933) system

Sampling Point	EC Period 2	EC Period 3	EC Period 4	%Na Period 2	%Na Period 3	%Na Period 4
1	Class 2, good	Class 2, good	Class 3, permissible	Class 1, perfect	Class 1, perfect	Class 1, perfect
2	Class 2, good	Class 2, good	Class 2, good	Class 1, perfect	Class 1, perfect	Class 1, perfect
3	Class 2, good	Class 2, good	Class 2, good	Class 1, perfect	Class 2, good	Class 2, good
4	Class 2, good	Class 2, good	Class 2, good	Class 2, good	Class 2, good	Class 2, good
5	Class 2, good	Class 2, good	Class 2, good	Class 2, good	Class 2, good	Class 2, good
6	Class 3, permissible	Class 2, good	Class 3, permissible	Class 2, good	Class 1, perfect	Class 1, perfect
7	Class 5, not suitable	Class 2, good	Class 3, permissible	Class 4, doubtful	Class 1, perfect	Class 2, good
8	Class 3, permissible	Class 2, good	Class 3, permissible	Class 2, good	Class 2, good	Class 2, good
9	Class 3, permissible	Class 2, good	Class 3, permissible	Class 2, good	Class 2, good	Class 2, good
10	Class 3, permissible	Class 3, permissible	Class 3, permissible	Class 2, good	Class 2, good	Class 2, good

3.6.2. Schofield (1935) system (EC, %Na, Cl, Sulphate)

Point 7 is in particularly bad situation in terms of EC. The pollution experienced in terms of EC in the period 4 is remarkable (*Table 2*).

3.6.3. Wilcox and Magistad (1943) system (EC, %Na, Cl, Boron)

According to Wilcox and Magistad (1943), continuous pollution was observed in terms of boron in the period 3 (*Table 3*).

Table 2. Results of water quality class according to Schofield (1935) system

Points	EC			%Na			Cl, meq l^{-1}			SO_4, meq.l^{-1}		
	Period 2	Period 3	Period 4	Period 2	Period 3	Period 4	Period 2	Period 3	Period 4	Period 2	Period 3	Period 4
1	Class 2, good	Class 2, good	Class 3, permissible	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect
2	Class 2, good	Class 2, good	Class 2, good	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect
3	Class 2, good	Class 2, good	Class 2, good	Class 1, perfect	Class 2, good	Class 2, good	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect
4	Class 2, good	Class 2, good	Class 2, good	Class 2, good	Class 2, good	Class 2, good	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect
5	Class 2, good	Class 2, good	Class 2, good	Class 2, good	Class 2, good	Class 2, good	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect
6	Class 3, permissible	Class 2, good	Class 3, permissible	Class 2, good	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect
7	Class 5, not suitable	Class 2, good	Class 3, permissible	Class 4, doubtful	Class 1, perfect	Class 2, good	Class 3, permissible	Class 1, perfect	Class 1, perfect	Class 4, doubtful	Class 1, perfect	Class 1, perfect
8	Class 3, permissible	Class 2, good	Class 3, permissible	Class 1, perfect	Class 2, good	Class 2, good	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect
9	Class 3, permissible	Class 2, good	Class 3, permissible	Class 2, good	Class 2, good	Class 2, good	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 2, good
10	Class 3, permissible	Class 3, permissible	Class 3, permissible	Class 2, good	Class 2, good	Class 2, good	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect	Class 1, perfect

Table 3. Results of water quality class according to Wilcox and Magistad (1943) system

Sampling Points	EC			%Na			Cl, meq l^{-1}			Boron, ppm		
	Period 2	Period 3	Period 4	Period 2	Period 3	Period 4	Period 2	Period 3	Period 4	Period 2	Period 3	Period 4
1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1
2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 2	Class 1
3	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 2	Class 3	Class 1
4	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 2	Class 3	Class 1
5	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 3	Class 1
6	Class 2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 2	Class 3	Class 1
7	Class 3	Class 1	Class 1	Class 2	Class 1	Class 1	Class 2	Class 1	Class 1	Class 3	Class 3	Class 1
8	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 3	Class 1
9	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 2	Class 1	Class 1
10	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 2	Class 1	Class 1

3.6.4. Wilcox (1948) Graphic system (EC and %Na)

According to Wilcox (1948), point 7 is not suitable for irrigation in the period 2. Compared to other periods, water quality began to decrease in the period 4 (*Table 4*).

Table 4. Results of water quality class according to Wilcox (1948) system

Sampling point	Intersection of EC and %Na		
	Period 2	Period 3	Period 4
1	Very good-good (class 1)	Very good-good (class 1)	Good-Useable (class 2)
2	Very good-good (class 1)	Very good-good (class 1)	Very good-good (class 1)
3	Very good-good (class 1)	Very good-good (class 1)	Very good-good (class 1)
4	Very good-good (class 1)	Very good-good (class 1)	Very good-good (class 1)
5	Very good-good (class 1)	Very good-good (class 1)	Very good-good (class 1)
6	Good-Useable (class 2)	Very good-good (class 1)	Good-Useable (class 2)
7	Not suitable (class 5)	Very good-good (class 1)	Good-Useable (class 2)
8	Good-Useable (class 2)	Very good-good (class 1)	Good-Useable (class 2)
9	Good-Useable (class 2)	Very good-good (class 1)	Good-Useable (class 2)
10	Good-Useable (class 2)	Good-Useable (class 2)	Good-Useable (class 2)

3.6.5. Thorne and Thorne (1951) graphic system (EC and %Na)

In this system, EC classes are classified between 1 and 5, while %Na values are grouped between A and E. For example, quality class of point 10 in the period 3, while it is in the class 2 in terms of EC, it is in the class 1 in terms of %Na. Especially, there is serious pollution in the period 2 at point 7 (*Table 5*).

Table 5. Results of water quality class according to Thorne and Thorne (1951) system

Sampling point	Intersection of EC and %Na		
	Period 2	Period 3	Period 4
1	1A	1A	2A
2	1A	1A	1A
3	1A	1A	1A
4	1A	1A	1A
5	1A	1A	1A
6	1A	1A	2A
7	4C	1A	2A
8	2A	1A	2A
9	2A	1A	2A
10	2A	2A	2A

3.6.6. Classification system of (USSL) USA salinity laboratory (1954) (EC and SAR)

In parallel with the results in Thorne and Thorne (1951) Graphic System, there is serious pollution especially in the period 2 at point 7. In the period 4, the pollution load increases to downstream (*Table 6*).

Table 6. Results of water quality class according to USSL (1954) system (USSL, 1954)

Sampling point	Intersection of EC and SAR		
	Period 2	Period 3	Period 4
1	C2S1	C2S1	C3S1
2	C2S1	C2S1	C2S1
3	C2S1	C2S1	C2S1
4	C2S1	C2S1	C2S1
5	C2S1	C2S1	C2S1
6	C3S1	C2S1	C3S1
7	C4S2	C2S1	C3S1
8	C3S1	C2S1	C3S1
9	C3S1	C2S1	C3S1
10	C3S1	C3S1	C3S1

3.6.7. Doneen (1959) potential salinity system (Cl and Sulphate)

At point 7, water pollution in period 2 has been identified as common to most classification systems. Water pollution, especially in the period 4, is constantly recurring (*Table 7*).

Table 7. Results of water quality class according to Doneen (1959) classification system

Sampling point	Period 2		Period 3		Period 4	
	Potential salinity, meq l^{-1}	Class	Potential salinity, meq l^{-1}	Class	Potential salinity, meq l^{-1}	Class
1	2.59	1	1.52	1	3.655	2
2	0.52	1	1.76	1	1.64	1
3	1.93	1	2.45	1	2.305	1
4	1.745	1	2.475	1	3.16	2
5	2.425	1	2.245	1	3.2	2
6	3.51	2	2.38	1	3.395	2
7	17.6	3	2.53	1	4.375	2
8	2.735	1	2.795	1	3.69	2
9	3.13	2	2.755	1	3.8	2
10	3.555	2	3.045	2	3.72	2

3.6.8. Doneen (1966) permeability indicator system (Sodium, bicarbonate and total cation)

In common with Doneen (1959) Potential Salinity and Doneen (1966) Permeability Indicator systems, water pollution in the period 4 is constantly recurring (*Table 8*).

3.6.9. Christiansen et al. (1977) classification system (EC, %Na, SAR, Na_2CO_3, Cl and Boron)

There is intense pollution, especially in terms of EC and Na_2CO_3 parameters. In terms of B in the period 3, the pollution load is very high in the middle points of the Karasu River. Except for the period 2 of point 7, there is no pollution in terms of %Na, SAR and Cl (*Table 9*).

Table 8. Results of water quality class according to Doneen (1966) classification system

Sampling point	Period 2		Period 3		Period 4	
	Permeability coefficient	**Class**	**Permeability coefficient**	**Class**	**Permeability coefficient**	**Class**
1	0.76	1	0.42	1	0.78	2
2	0.49	2	0.48	1	0.37	2
3	0.83	2	0.80	2	0.84	2
4	0.70	1	0.83	2	0.85	2
5	0.71	1	0.79	2	0.84	2
6	0.83	2	0.74	1	0.84	2
7	0.96	2	0.68	1	0.90	2
8	0.71	1	0.80	2	0.85	2
9	0.76	1	0.85	2	0.85	2
10	0.76	1	0.82	2	0.86	2

3.6.10. Soifer (1987) graphic system (EC and SAR)

According to the graphic system of Soifer (1987), point 2 has very low pollution load and is the cleanest point (*Table 10*).

Table 10. Results of water quality class according to Soifer (1987) graphic classification system

Sampling point	Period 2 Class	Period 3 Class	Period 4 Class
1	III_1	II	III_2
2	I	II	I
3	III_3	III_3	III_3
4	III_3	III_3	III_3
5	III_3	III_3	III_3
6	III_5	III_3	III_4
7	III_5	III_3	III_5
8	III_4	III_4	III_4
9	III_4	III_4	III_4
10	III_4	III_4	III_4

I: Suitable for all crops and soils, II: Suitable for most crops and soils, III: Limited availability, IV: Can be used in certain condition, V: Not suitable

3.6.11. "2000/60/EC Water Framework Directive" and the "Surface Water Quality Regulation" harmonized within its scope (Official newspaper in 30th November 2012 and numbered 28483)

Generally, values above critical thresholds were obtained for Al and B parameters. For this reason, the Karasu river is not suitable for irrigation in terms of Al and B. It is necessary to be careful, especially in agricultural irrigation at points 6 and 7 (*Table 11*).

Table 11. Water quality class results according to surface water quality regulation (Anonymous, 2023)

Parameters	Sampling point									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
pH	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
EC	good	good	good	good	good	mean	mean	good	good	good
Manganese	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good
Aluminium	✕	✕	✕	✕	✕	✕	✕	✕	✕	✕
Arsenic	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Boron	✔	✔	✕	✕	✕	✕	✕	✕	✔	✔
Iron	✔	✔	✔	✔	-	✔	✔	✔	✔	✕
Chromium	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Lead	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

Table 9. Results of water quality class according to Christiansen et al. (1977) classification system

Points	**EC (dS m^{-1})**			**%Na**			**SAR**			**Na_2CO_3 (meq l^{-1})**			**Cl, meq l^{-1}**			**Boron, ppm**		
	Period 2	**Period 3**	**Period 4**	**Period 2**	**Period 3**	**Period 4**	**Period 2**	**Period 3**	**Period 4**	**Period 2**	**Period 3**	**Period 4**	**Period 2**	**Period 3**	**Period 4**	**Period 2**	**Period 3**	**Period 4**
1	Class 2	Class 1	Class 2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 5	Class 3	Class 6	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1
2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 4	Class 3	Class 2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1
3	Class 2	Class 2	Class 2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 6	Class 6	Class 6	Class 1	Class 1	Class 1	Class 3	Class 4	Class 1
4	Class 2	Class 2	Class 2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 6	Class 6	Class 6	Class 1	Class 1	Class 1	Class 2	Class 6	Class 1
5	Class 2	Class 2	Class 2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 6	Class 6	Class 6	Class 1	Class 1	Class 1	Class 1	Class 6	Class 1
6	Class 3	Class 2	Class 2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 6	Class 5	Class 6	Class 2	Class 1	Class 1	Class 3	Class 6	Class 1
7	Class 5	Class 2	Class 2	Class 3	Class 1	Class 1	Class 3	Class 1	Class 1	Class 6	Class 5	Class 6	Class 3	Class 1	Class 1	Class 4	Class 6	Class 1
8	Class 2	Class 2	Class 2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 6	Class 6	Class 6	Class 1	Class 1	Class 1	Class 1	Class 6	Class 1
9	Class 2	Class 2	Class 2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 6	Class 6	Class 6	Class 1	Class 1	Class 1	Class 2	Class 1	Class 1
10	Class 2	Class 2	Class 2	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 6	Class 6	Class 6	Class 1	Class 1	Class 1	Class 2	Class 1	Class 1

4. Discussion and Conclusions

Kapdı and Aşık (2021) determined that SAR varies between 3.1 and 3.5 in the Uşak Güllübağ lake water. Karademir et al. (2020) determined that the water resources in Iğdır are suitable for the usage of farm animals. Topçu and Taş (2020) determined that the Çanakkale Biga plain have class 1 water in the most of wells. Tepe and Kutlu (2019) determined that the Karkamış Dam Lake had high water quality (1st class) in Gaziantep in 2015. In parallel with these results in Bilecik (Karasu), Uşak, Iğdır, Çanakkale and Gaziantep, the presence of high water quality class and low SAR values supports that non-industrialized, low populated cities have high water quality. Ağca and Doğan (2020) determined that Asi river is in the "Very salty water" class. While one water quality parameter is high, another may be low. Therefore, crops suitable for different periods (seasons) and points (areas) should be decided by looking at the ions with obvious deficiency/excess. Diri (2018) found that the water quality of the Konya Watershed and the Sakarya Watershed were not suitable for irrigation in general. Kar and Leblebici (2020) determined that SO_4 and K in the Yamula Dam lake in Kayseri are mainly effective parameters in evaluating the quality of this lake. Dündar (2008) determined that the pollution in the Lower Sakarya River in 2007 was caused by fertilizers in agricultural areas. Therefore, research on pollution caused by SO_4 and K-component fertilizers might be concentrated in agricultural cities such as Konya, Kayseri and Sakarya. Akkan and Mutlu (2022), Osmanoğlu and Özalp (2023) determined that the water quality in the Artvin Çoruh River watershed and Murgul stream were in the bad class. Besides, they stated that the river water had a high heavy metal concentrations at the exit of the mining area. Therefore, if non-industrialized and low-populated cities are to be examined, it is much more important to examine different parameters of water quality in special (sensitive) regions such as mining areas.

When these informations in the literature were compared and evaluated together with the results in this study, it was understood that heavy metal pollution did not cause much of a problem in non-industrialized cities such as Bilecik. Besides, it was understood that the most common element among heavy metals was Pb.

Consequently, the results showed that water quality changed spatially and contamination information occurred between the beginning and the flow into the Sakarya River. According to the results of the period 2 (Spring), especially at points 6 and 7, which are close to the city center, Na, HCO_3 and Cl ions concentrations were very high. When the SAR value is examined, which is an important parameter in controlling suitability for agricultural irrigation, it has been understood that the SAR values of all points are in the lowest class (Water with low sodium) and that they can be used safely in irrigation. Even so, irrigation of stone fruit orchards with this water may reduce fruit yield because low-sodium water with low SAR value can affect stone fruits that are sensitive to alkalinity (Ayyıldız, 1983; Tüzüner, 1990). In particular, it is recommended to use these waters in stone fruit orchards near point 7, provided that sandy and organic soil is available.

For the period 2 (Spring), as a result of water samples taken from 10 points on 03.03.2023, it was understood that the Karasu River was extremely polluted around Vezirhan-Bayırköy before flowing into the Sakarya River. It is thought that this situation is caused by the increase in industrialization in the region. At point 10, which is the last sampling point, an increase in water quality was observed. It is thought that this situation may be caused by mixing with a clean water source in tributary streams flowing into the Karasu River. For the period 3 (Summer), as a result of water samples taken from 9 points on 06.07.2023, it is seen that especially Boron values are high. Besides, heavy metal pollution, especially Al, attracts attention. For the period 3 (Fall), as a result of water samples taken from 10 points on 08.09.2023, it is understood that water quality deteriorates as you observe from upstream to downstream.

As a result of all analyzes being completed and the study completed, the SAR and RSC values of all periods, seasons and points were classified as "Very Good-Safe (C1S1)". When the SO_4 results were examined, the period 2 of point 7 was in class 4 (Can be used with caution) with a value of 15.67 meq l^{-1} (752.16 ppm), and the period 4 of point 9 was in the class 2 (good) with a value of 6.40 meq l^{-1} (307.2 ppm). Except for these, the class of all periods and points in terms of sulphate was "Very good (class 1)". In the period 2 of point 7 (Spring) and in the period 4 of point 9 (Fall), it is recommended that local farmers should be careful when using the water.

The general conclusions reached about water quality classification systems are as follows: According to Schofield (1933 and 1935) systems, point 7 is in particularly bad situation in terms of EC. In addition, the pollution experienced in terms of EC in the period 4 is remarkable. According to Wilcox and Magistad (1943), continuous pollution was observed in terms of boron in the period 3. According to Wilcox (1948), point 7 is not suitable for irrigation in the period 2. According to Thorne and Thorne (1951) and USSL (1954), the pollution load increases to downstream in the period 4. At point 7, water pollution in period 2 has been identified as common to most classification systems. In common with Doneen (1959 and 1966) systems, water pollution in the period 4 is constantly recurring. According to Christiansen et al. (1977), there is intense pollution in terms of EC and Na_2CO_3 parameters. According to Soifer (1987), point 2 is the cleanest point. The fact that all discharge points of Bilecik Province are collection-spillage points is one of the main reasons for the poor water quality of point 7. As a result, Karasu river is not suitable for irrigation in terms of Al and B.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

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