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Research Article

Assessing the Relationship Between Electrical Conductivity and Total Dissolved Solids of Different Water Resources in a Large-scale Irrigation Scheme in the Eastern Mediterranean Basin of Turkiye

Mahmut CETIN[1], Omar ALSENJAR[1]*, Angela HIUHU[2], Muhammet Said GOLPINAR[1], Muge ERKAN CAN[1]

ABSTRACT

Climate change and population growth have led to changes in both the quantity and quality of water resources. In Turkiye, a Mediterranean country, over 75% of its surface water is used for irrigation. Given the average annual precipitation (574 mm) in Turkiye, except for the Black Sea Region, all arable land in the country relies on irrigation to maintain sustainable food production. Agriculture constitutes 6% of Turkiye's gross domestic product (GDP), with exports including crops such as cotton, corn, cereals, pulses, oilseeds, nuts, citrus orchards, and various fruits. As a result, the water provided for irrigation in any irrigation system must meet acceptable irrigation water quality standards to ensure the sustainability of irrigation and food security. This study aims to a) investigate two essential irrigation water quality parameters: Electrical Conductivity (EC) and Total Dissolved Solids (TDS), and b) evaluate their empirical relationship using samples collected from various water sources within a large-scale irrigation district, covering an area of 9495 ha in the Eastern Mediterranean Region of Turkiye. Water samples were collected over a period of one water year, from October 2022 to September 2023. A total of 13 locations were considered: a) Seven agricultural drainage channels, b) Four irrigation water sources (Seyhan River, Ceyhan River, one spring and one groundwater well), c) Two outlets - the existing research catchment outlet and the other downstream. The EC values of water samples were determined using a benchtop EC meter in the laboratory, and TDS was determined by the gravimetric method. The results showed that there was a statistically significant correlation (r≥0.98) between EC and TDS across all water samples. The proportionality constant (K) ranged predominantly between 400 and 800 and was consistent with literature reporting a linear relationship between EC and TDS. Research findings suggest that the quality of different water supplies is suitable for irrigation of all kinds of crops grown in the Lower Seyhan Plain in Turkiye. The overall characteristics of the average annual EC and TDS values are reflected in the proposed equations for each water body. However, in future research, we recommend that water sample volumes should be at least 100 ml to provide more accurate results for water quality assessment.

Keywords: Electrical conductivity (EC), total dissolved solids (TDS), water quality, irrigation catchment scale, Lower Seyhan Plain (LSP)

Türkiye'nin Doğu Akdeniz Havzasındaki Büyük Ölçekli Bir Sulama Şebekesinde Farklı Su Kaynaklarının Elektriksel İletkenliği ve Toplam Çözünmüş Katı Madde Arasındaki İlişkinin Değerlendirilmesi

ÖZ

İklim değişikliği ve nüfus artışı, su kaynaklarının hem miktarında hem de kalitesinde değişikliklere neden olmaktadır. Bir Akdeniz ülkesi olan Türkiye'de, yüzey sularının %75'ten fazlası sulama amacıyla kullanılmaktadır. Yıllık ortalama 574 mm yağış düşmesine rağmen, Karadeniz Bölgesi hariç olmak üzere, Türkiye'deki tarıma elverişli tüm arazilerde, sürdürülebilir tarımsal faaliyetler ve gıda güvenliği sulamaya

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[1]Cukurova University, Department of Agricultural Structures and Irrigation, Adana, Turkey
[2]University of Nairobi, Department of Environmental & Biosystems Engineering, Nairobi, Kenya
*Corresponding Author: omarsenjar@yahoo.com

bağlıdır. Tarım, Türkiye'nin gayri safi yurt içi hasılasının (GSYİH) %6'sını oluşturmakta olup, ihracat ürünleri arasında pamuk, mısır, tahıllar, baklagiller, yağlı tohumlar, fındık, narenciye bahçeleri ve çeşitli meyveler bulunmaktadır. Dolayısıyla, gıda güvenliğini sağlamak için, sulamada kullanılan suyun, kabul edilebilir kalite standartlarını karşılaması gerekmektedir. Bu çalışmanın amacı: a) İki temel sulama suyu parametresini (Elektriksel İletkenlik (EC) ve Toplam Çözünmüş Katı Madde (TDS) analiz edip, irdelemek ve b) Türkiye'nin Doğu Akdeniz Bölgesi'nde 9495 hektarlık bir alanı kapsayan büyük ölçekli bir sulama bölgesindeki çeşitli su kaynaklarından toplanan su örneklerinin EC ve TDS değerleri elde ederek, aralarındaki ampirik ilişkileri değerlendirmektir. Analiz edilen su örnekleri, 1 Ekim 2022 ile 30 Eylül 2023 tarihleri arasında bir su yılını kapsayan dönem boyunca toplanmıştır. Araştırmada, toplam 13 farklı konumdan alınan su örneklerinin kalitesi dikkate alınmıştır: a) Yedi tarımsal drenaj kanalı, b) Dört sulama suyu kaynağı (Seyhan Nehri, Ceyhan Nehri, bir kaynak ve bir yer altı suyu kuyusu), c) İki drenaj çıkış noktası (mevcut araştırma havzası çıkışı ve bu çıkışın mansap noktasında yer alan bir lokasyon). Su örneklerinin EC değerleri laboratuvarda EC metre kullanılarak, TDS değerleri ise gravimetrik yöntemle belirlenmiştir. Tüm su örnekleri için, EC ve TDS değerleri arasında istatistiksel anlamda önemli bir korelasyon ($r \geq 0.98$)) bulunmuştur. EC ve TDS arasındaki doğrusal ilişkiyi gösteren orantı sabiti (K) genellikle 400-800 arasında değişmiştir. Bu değerlerin, EC ve TDS arasındaki doğrusal ilişkiyi gösteren literatürle tutarlı olduğu tespit edilmiştir. Araştırma bulguları, Türkiye'nin Aşağı Seyhan Ovası'nda bahsi geçen su kaynaklarındaki sulama suyu kalitesinin, yörede yetiştirilen bitkilerin sulanmasına uygun olduğuna işaret etmiştir. Her su örnekleme noktası için belirlenen deneysel ilişki denklemleri, yıl boyunca ortalama EC ve TDS değerlerinin genel özelliklerini yansıtmıştır. Bununla birlikte, gelecekte yapılacak olan araştırmalarda ve su kalitesi değerlendirmelerinde daha doğru ve temsili sonuçlar elde etmek için, su örneklem hacimlerinin en az 100 ml olması önerilmiştir.
Anahtar Kelimeler: Elektriksel iletkenlik (EC), toplam çözünmüş katı madde (TDS), su kalitesi, sulama şebekesi ölçeği, Aşağı Seyhan Ovası (ASO)

ORCID ID (Yazar sırasına göre)
0000-0001-5751-0958, 0000-0001-9471-794X, 0000-0002-8476-0191, 0000-0002-3536-4563, 0000-0002-0744-1496

Introduction

As all living things use water for a variety of purposes, the quality and quantity of water are of great importance to humanity. Water quality describes the physical, chemical, thermal, and biological properties of water (Ritchie and Schiebe, 2000). Water quality depends on many factors, such as climate, geographical location, topography, and geological structure. In drought-prone areas, such as the Mediterranean region, the quality and quantity of water are particularly sensitive. Therefore, monitoring water quality is particularly important in arid and semi-arid environments (Cetin et al., 2020). Turkiye is a Mediterranean country (Alsenjar et al., 2022), with a semi-arid climate characterized by hot, dry summers and cool, rainy winters. Accordingly, approximately 76% of all water is used for agricultural irrigation (Cetin et al., 2023). As a result, every drop of water is thus crucial and valuable for agricultural purposes. Given seawater intrusion, continuous monitoring, assessment, and improvement of the quality of water are critical for managing the quality of surface water and groundwater (Anyango et al., 2024; Lech et al., 2016; Ritchie and Schiebe, 2000). Water quality tests are either carried out *in-situ* or the samples are brought to the laboratory for further experiments/analysis (Ritchie and Schiebe, 2000). In this context, Zaman et al. (2018) reported that the four basic criteria for evaluating irrigation water quality are water salinity, i.e., EC, sodium hazard (SAR), residual sodium bicarbonate, and ion toxicity. Cetin et al. (2020) addressed the importance of *total dissolved solids, i.e.,* TDS, in assessing irrigation water quality.

Total dissolved solids (TDS) is defined as the total amount of dissolved solids in water, which quantifies the amount of material dissolved in water (Anyango et al., 2024; Thirumalini and Joseph, 2009). TDS exist in many forms: salts, metals, cations, and anions dissolved in water

(Dede et al., 2013). Irrigation water with a high TDS content may cause soil salinization in one way or another. In turn, TDS is an indicator of soil salinity, which is affected by ongoing agricultural practices. The majority of salts found in water, including calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), chlorides (Cl), and sulfates (SO_4^{-2}), play essential roles in supporting crop growth. The changes in these salts also lead to changes in the magnitude or degree of electrical conductivity (EC). However, an excess of any quantity can result in a reduction in crop yield. TDS is also referred to as part per million (ppm), and its units are milligrams per liter (mg l^{-1}).

On the other hand, EC is defined as the ionic strength of water that enables to transfer electrical current. The ionic strength is represented by the diversity of cations and anions in water (Dede et al., 2013). EC is commonly measured in either dS m^{-1}, dS cm^{-1}, or µS cm^{-1}. The quantification of TDS is cumbersome, so EC is measured in the laboratory or field, and the measured value gives an indicator of TDS using Equation 1. Accordingly, some EC instruments provide an approximate or rough estimation of TDS based on EC. Therefore, this forecast is subject to a degree of uncertainty. However, determination of TDS is important for understanding salinity levels in water, especially in areas surrounded by the sea, as in the case of our study area. TDS is related to EC by a factor known as the *constant of proportionality* (K), which varies depending on the quality of water, as shown in Equation 1 (Rusydi, 2018). It has been shown in the literature that the likely values of K range from 400 to 800.

$$\mathrm{TDS} = \mathrm{K} \times \mathrm{EC} \quad (1)$$

The relationship between TDS and EC was measured using the *correlation coefficient (r)* and (Choo-in, 2019) explains the level of this relationship in Table 1.

Table 1. Degree of correlation between TDS and EC (Choo-in, 2019)

Correlation Coefficients (*r*)	**Level of Relationship**
0.91-1.00	Very High
0.71-0.90	High
0.51-0.70	Moderate
0.31-0.50	Low
0.00-0.30	Very Low

The TDS concentration in a water source indicates the presence of inorganic salts and small amounts of organic matter in the water, and EC is a surrogate measure of TDS. Therefore, EC was used to measure the water's ability to conduct electrical current. In turn, to ensure that water quality is suitable for irrigation, EC and TDS are key indicators for determining the quality of different water sources available in an agricultural catchment. Given this, the study was designed to achieve two objectives:

a) To evaluate the relationship between TDS and EC for different types of water sources in an agricultural catchment, i.e., the Akarsu Irrigation District (AID), which covers an area of 9495 ha situated in the eastern Mediterranean region of Turkiye.

b) To apply these relationships in regions where only EC measurements are available, thereby allowing determination of TDS for different water types.

Materials and Methods

Study Area and Data Used

The study area, known as the Akarsu Irrigation District (AID), is situated within a catchment area covering 9495 ha in the Lower Seyhan Plain (LSP) of Turkiye (Alsenjar et al., 2023a; 2023b;

Kaman and Cetin, 2022). The terrain in this area is predominantly flat and uniform. In the AID, the yearly mean, minimum, and maximum air temperatures were 18.9 °C, 9.0 °C, and 31.0 °C, respectively. In addition, the average annual rainfall in the catchment area and its surroundings is 649.5 mm (Cetin et al., 2020). The winter season in Turkiye typically lasts from December 1st to the end of February, while the summer season extends from June 1st to the end of August. Figure 1 shows the location of the irrigation district and its surroundings. Continuous irrigation over a long period has affected the shallow water table and water quality in this semi-arid region (Cetin et al., 2020). Therefore, the continuous management of water quality is crucial in this area.

The AID, located in the eastern Mediterranean region of Turkiye, is shown in Figure 1. The dotted lines (▬ ▪ ▪ ▬) representing drainage channels and the arrows indicate the direction of the water flow. As seen in Figure 1, within the district, L6 (fed from the Seyhan River) and L9 (from the Ceyhan River) serve as irrigation water input points, along with a spring and L8 which accesses groundwater. L2 and L11 are locations where drainage water enters the study area, while DO1, DO2, DO3, DO5, and L10 are outlets for drainage waters within the study area. L4 serves as the main drainage outlet of the catchment, and L12 is an outfall located downstream of the study area.

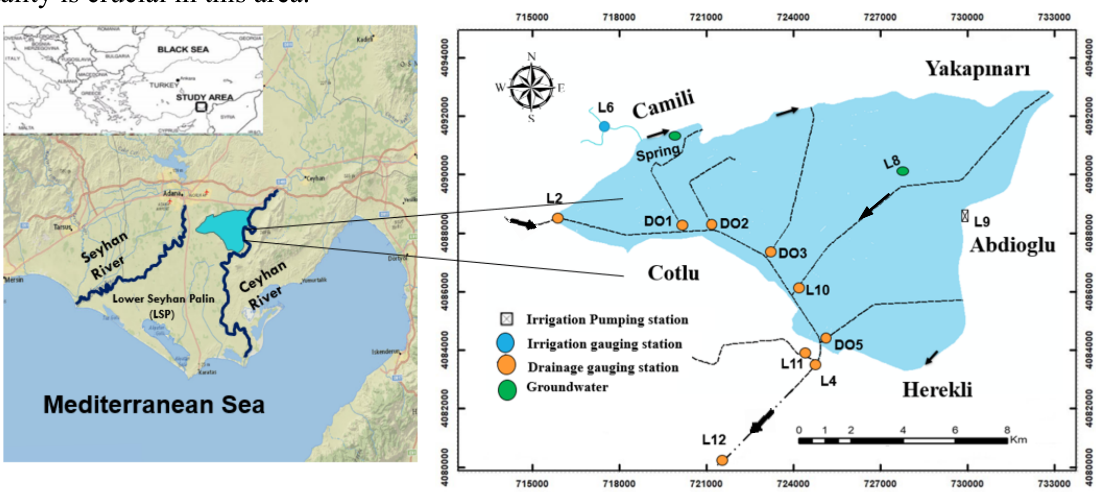


Figure 1. Location of the study area in Turkiye and the Lower Seyhan Plain (LSP) Irrigation Project area

Water Sampling

Water samples were collected over a period of one water year, from October 2022 to September 2023, at thirteen locations as shown in Figure 1. Daily water samples were collected using an automatic water sampler installed at the main drainage outlet (L4) within the study area and at L12, as shown in Figure 1. In contrast, water samples from other irrigation and drainage points (inflows and outflows) were collected every two weeks. In particular, L6 and L9 represent irrigation diversion locations from the Seyhan and Ceyhan Rivers, respectively. L9 also serves as a pumping station during the peak irrigation season when there is a shortage of water in the main irrigation canal. This station transfers irrigation water from the Ceyhan River to the study area. Additionally, a shallow groundwater well, L8, and a spring within the study area were also sampled. Furthermore, water samples were collected from the drainage inlets at L2 and L11 and from the drainage outlets of DO1, DO2, DO3, L10, and DO5, which are located in the study area. The typical volume of water collected at each sampling location was approximately 250 ml. However, the majority of this volume was used for other analyses, such as Na, Ca, Mg, K, Cl, CO_3, HCO_3, suspended sediment concentrations, etc. Consequently, the remaining volume of water, which ranged from 20 to 110 ml, was used for EC and TDS analyses at each sampling location. Table 2 shows the number of water samples collected and the volume of each water sample used for EC and TDS analysis at the Agricultural Structures and Irrigation Laboratory of Cukurova University, Adana, Turkiye.

Table 2. The number of water samples collected and the volume of each sample used in the EC and TDS analyses

Sample Description	Sample Location	Number of samples	Volume (ml)
Water Sources	Spring	12	48-61
	Groundwater (L8)	15	50-56
	L6 (irrigation, Seyhan River)	7	32-82
	L9 (irrigation, Ceyhan River)	10	29-67
Drainage Outlets of the Study Area	L4 (outlet within the study area)	60	20-110
	L12 (outside the study area)	82	20-89
Drainage (Inputs and outputs within the study area)	DO1(output)	10	22-86
	DO2(output)	9	30-57
	DO3(output)	11	33-58
	DO5(output)	11	30-59
	L2 (input)	8	33-58
	L10 (output)	9	40-115
	L11 (input)	9	29-59

Linear Regression Analysis Between EC and TDS

In this study, linear regression models were applied to determine the relationship between EC and TDS data collected from multiple sampling sites. For each sampling site, a linear equation in the form of $TDS = K \times EC$ was derived, and the slope (i.e., the *constant of proportionality)* was determined by Rusydi (2018) and Cetin et al. (2020).

Laboratory Analysis: Electrical Conductivity Measurements and Determination of Total Dissolved Solids

As explained above, water samples were collected from 13 sampling sites and placed in well-labeled bottles displaying the respective dates of collection and sample site. Water samples were preserved in accordance with the standards (25 °C) (Boyd, 2020). Water samples were filtered to remove any particulate matter. The EC values of the water samples were determined using a benchtop EC meter. As recommended by Boyd (2020), the water sample was gently shaken, and the EC meter probe was inserted into the sample. A reading was taken after displaying a constant figure on the conductivity meter screen. The probe was washed with distilled water before use in subsequent tests.

TDS was determined using the gravimetric method (EnviroMail, 2022). A dry clean beaker was weighed, its weight recorded, and a known volume of the water sample was poured into the beaker. The beaker was placed in the oven to dry until there was no difference in the dry weight of the beaker (Boyd, 2020). The difference in weight was recorded as the weight of the solids. This process was repeated for all samples. Measurement details are available in Boyd (2020), Golpinar et al. (2022), and EnviroMail (2022), among others. Equation 2 shows how TDS was calculated.

$$TDS = K_{con} \times \frac{Weight\ of\ soilds\ (mg)}{Volume\ of\ water\ sample\ (l)} \quad (2)$$

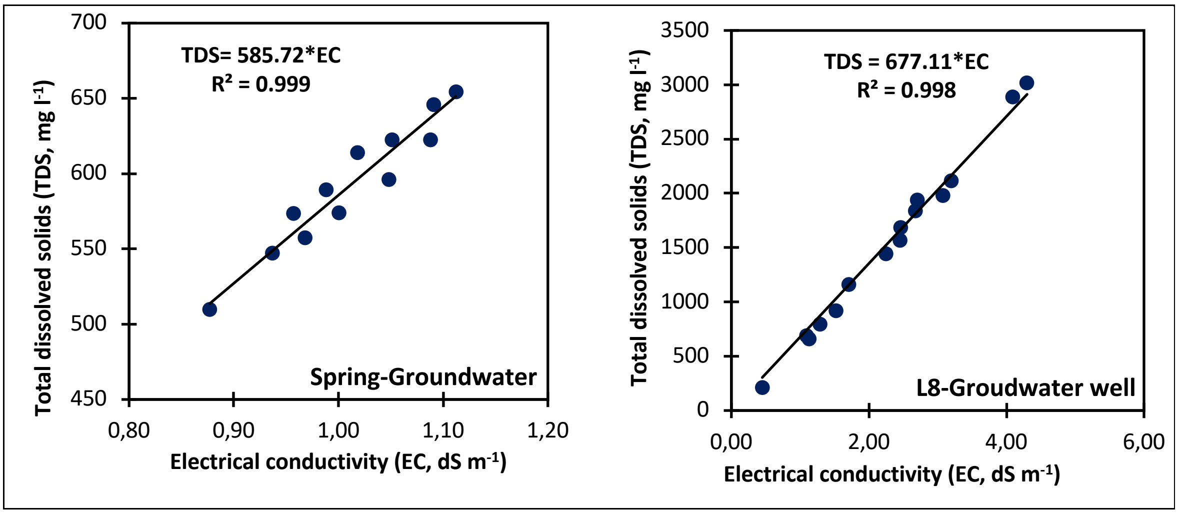
K_{con} is a factor that converts the unit of mg per volume of water sample used in the analysis to the standard unit of mg per liter (mg l^{-1}).

Graphs comparing TDS and EC were plotted and analyzed to diagnose potential data inconsistencies. The graphs show both *the constant of proportionality (i.e., K)* and the *determination coefficient (R^2)* of the linear regression line.

Results and Discussion

As can be seen from the details given in the material and method section, the data included EC readings from the EC meter, the weight of the empty beaker, the weight of the beaker containing dried solids, and the volume of water for each sample. This data was recorded and analyzed using an Excel sheet. The TDS was calculated using Equation 2, and its values were plotted against the EC values in graphs as shown below (Figure 2 - Figure 4). The relationship between TDS and EC was determined by calculating the *coefficients of determination*, *correlation coefficient*, and *constant of proportionality* using linear regression. Mathematical forms of the relationships between EC and TDS, *the proportionality coefficient K,* and the *coefficient of determination R^2* obtained from the regression analysis are shown in Table 3 for the sampling locations. This analysis allowed us to derive conclusions about the degree of water quality at the sampling sites and the nature of the relationship between EC and TDS.

As seen in Figure 3, Figure 4a, and Figure 4b, in the graphical representation of the data, the sampling sites, based on the water sources, were grouped into three categories to help water quality experts and practitioners make rational decisions and/or interpretations about the quality of different water sources: irrigation inputs and outputs within the study area, and drainage outlets within and outside the study area.



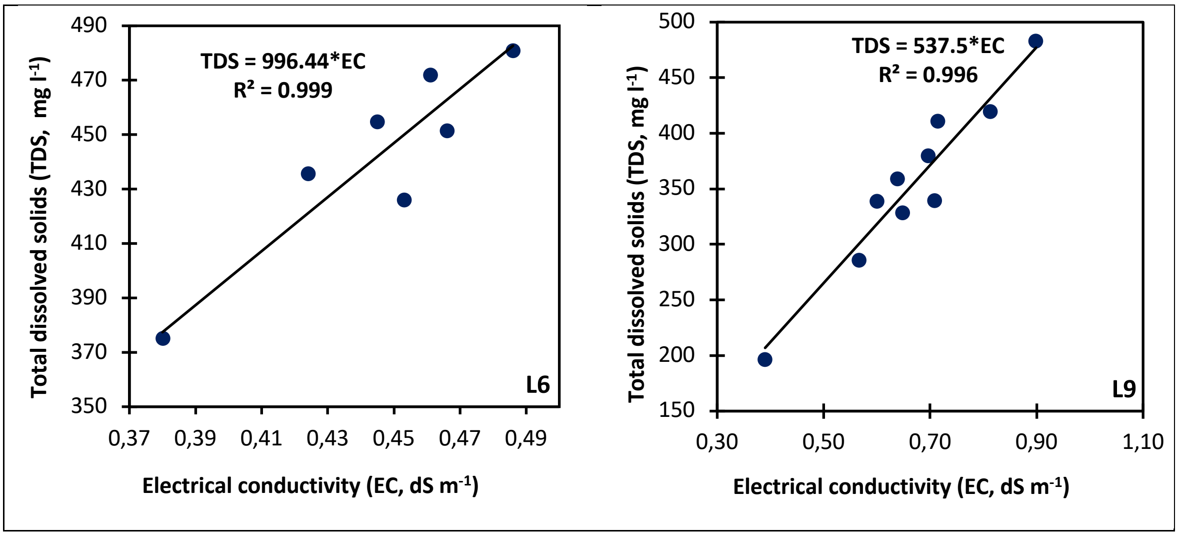


Figure 2. Post plot of EC versus TDS data acquired from irrigation inputs (L6 from Seyhan River, L9 from Ceyhan River) and groundwater (Spring and L8), the mathematical form of the linear relationship between EC and TDS, and the coefficient of determination of the relationship by sampling sites

Table 3. Summary of the relationships between TDS and EC, *proportionality coefficients (K),* and *determination coefficients (R^2)* according to water source and sampling location

Sample Description	Sample Location	*TDS=K*EC*	Determination Coefficients (R^2)
Water Irrigation Sources	Spring	TDS=585.72*EC	0.9997
	Groundwater (L8)	TDS=677.11*EC	0.9976
	L6 (irrigation, Seyhan River)	TDS=996.44*EC	0.9991
	L9 (irrigation, Ceyhan River)	TDS=537.50*EC	0.9959
Drainage Outlets in the Research Area	L4 (outlet within the study area)	TDS=434.50*EC	0.9935
	L12 (outside the study area)	TDS=537.77*EC	0.9916
Drainage (Inputs and Outputs Within the Study Area)	DO1(output)	TDS=565.78*EC	0.9958
	DO2(output)	TDS=597.68*EC	0.9982
	DO3(output)	TDS=590.59*EC	0.9995
	DO5(output)	TDS=552.80*EC	0.9986
	L2 (input)	TDS=609.76*EC	0.9973
	L10 (output)	TDS=562.26*EC	0.9974
	L11 (input)	TDS=815.93*EC	0.9944

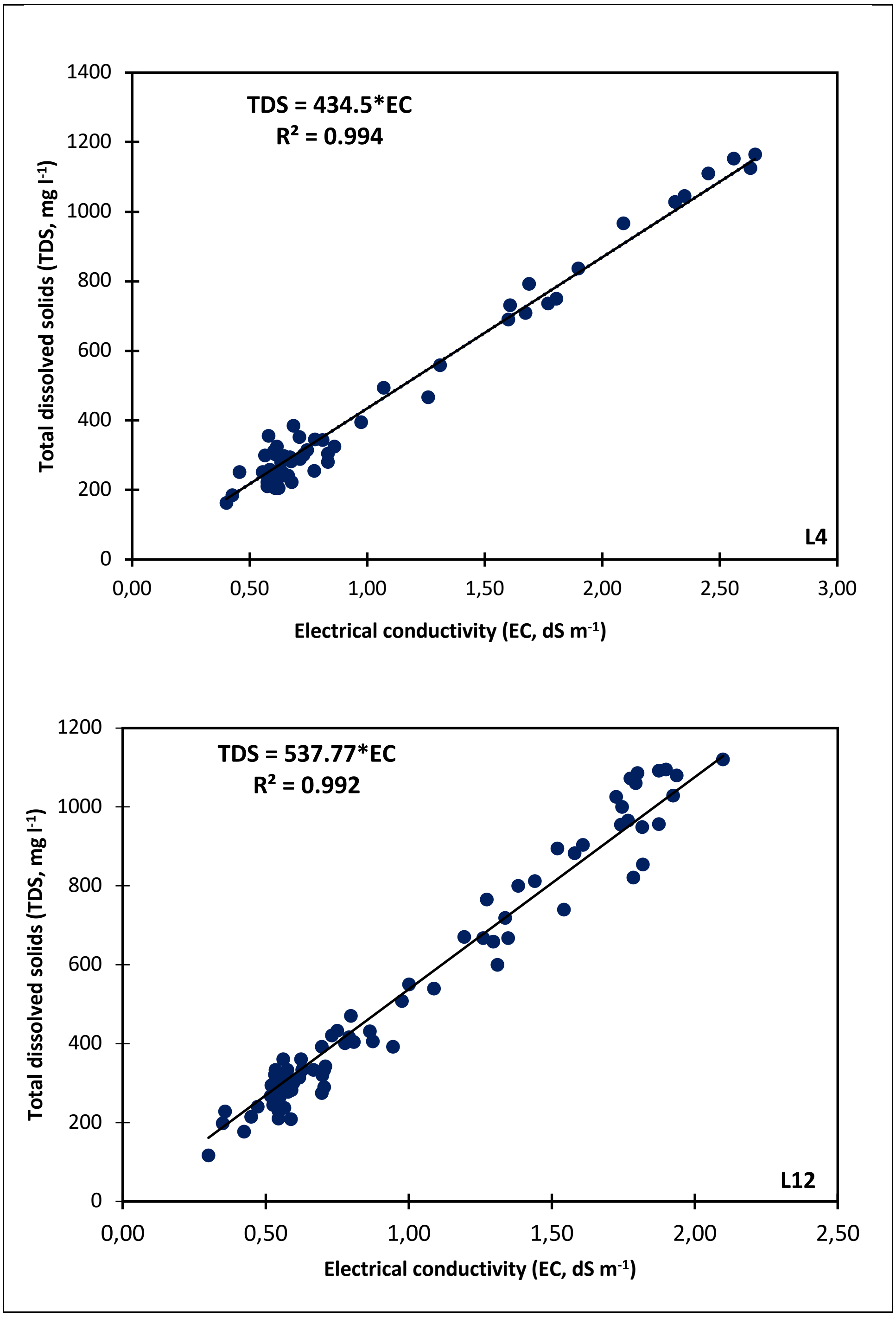


Figure 3. Post plot of EC versus TDS data acquired from drainage outlets: the mathematical form of the linear relationship between EC and TDS, and the coefficient of determination of the relationship by sampling sites, i.e., L4 and L12

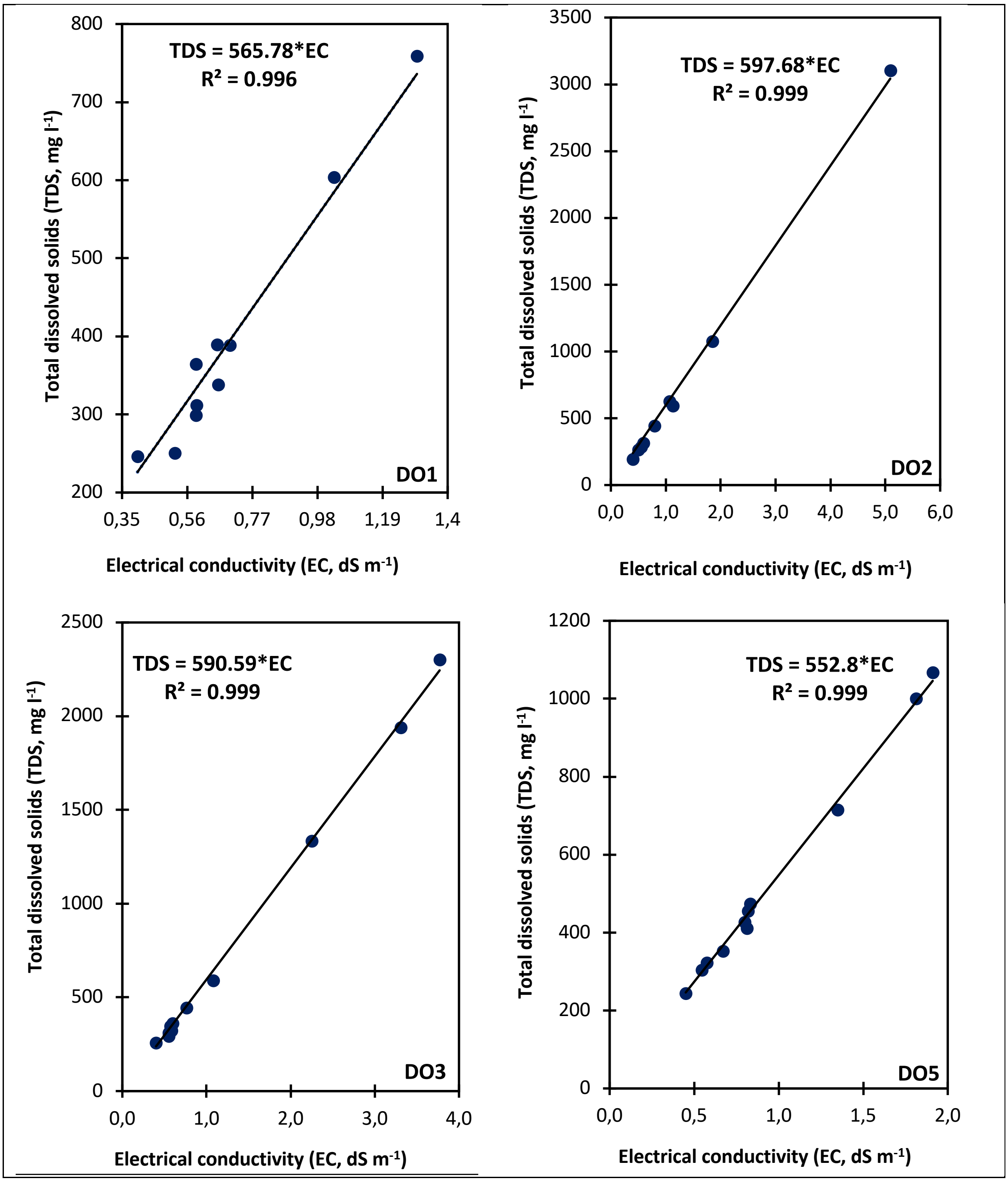


Figure 4a. Post-plot of EC versus TDS data acquired from drainage outlets (DO1, DO2, DO3, DO5), the mathematical form of the linear relationship between EC and TDS, and the coefficient of determination of the relationship by sampling sites

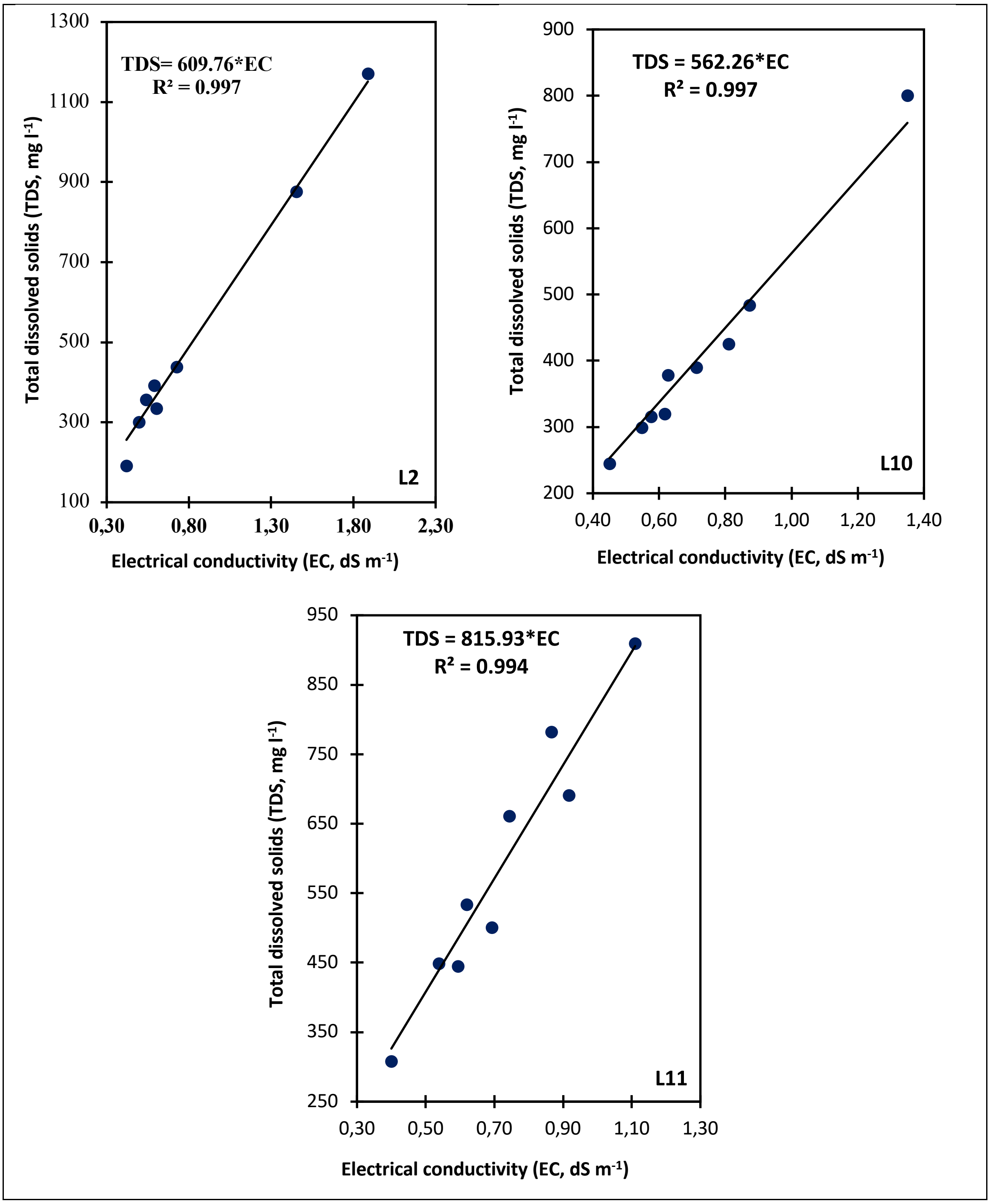


Figure 4b. Post plot of EC versus TDS data acquired from drainage outlets (L2, L10, L11), the mathematical form of the linear relationship between EC and TDS, and the coefficient of determination of the relationship by sampling site

As explained before, the regression analysis results are summarized in Table 3. Table 3 shows the different equations of TDS and EC as well as the *constant of proportionality factor (K in mg* l^{-1} *(dS* $m^{-1})^{-1}$ *unit)* values across all sampling sites.

The values of the *constant of proportionality factor K, i.e., the ratio of TDS/EC,* ranged from

434.50 to 996.44. The highest K value was recorded at L6, a water source from the Seyhan River, while the lowest K value was observed at L4, the outlet of the irrigation catchment. For drainage outputs within the study area (L2, L10, L11, DO1, DO2, DO3, DO5), the K values generally ranged from 553 to 598. Surprisingly, the EC values for DO5 and L10 were almost identical, indicating minimal differences in K values between these two sampling sites. Rusydi (2018) pointed out that the EC of natural waters for irrigation varies from 0.5 $dS\ m^{-1}$ to 3.0 $dS\ m^{-1}$ and the *constant of the proportionality factor K* changes between 550 $mg\ l^{-1}\ (dS\ m^{-1})^{-1}$ and 750 $mg\ l^{-1}\ (dS\ m^{-1})^{-1}$. The bypass flow contribution from the irrigation canal outlets to the drainage outlets may account for this similarity. On the other hand, the similarity of K values at DO5 and L10 can be attributed to the fact that citrus orchards were cultivated at both DO5 in Figure 4a and L10 in Figure 4b, resulting in similar agricultural practices compared to other points like DO1, DO2, and DO3, where winter and summer crops (such as cereals, cotton, and corn) were grown. Factors such as fertilizer use, crop type, soil type, and groundwater likely influence the EC and TDS values at the drainage points. Figure 4b shows that the K value at L11 was higher (nearly 816) than the other drainage outputs in the study area. Since this drainage canal was partially influenced by the sewage of the village of Cotlu, the ionic composition of the drainage water at L11 may differ from that at the other sites. On the other hand, effluents from L11 originate from outside the study area, where agricultural practices differ slightly from those within the AID. The K value at L4 (434.50) was lower than that at L12 (537.77), likely due to differences in crop types and farming practices as well as differences in irrigation water and base flow contributions. However, the R^2 values at all points were high, close to 1.0, ranging from 0.9916 to 0.9991. Based on the criteria given in Table 1, it is concluded that the correlation and linear relationship between EC and TDS is statistically significant at alpha = 0.01, and the level of the relationship is "*very high*". The results of this study confirmed that the quality of irrigation water diverted from the Seyhan and Ceyhan Rivers met the allowed limits for irrigation practices.

Conclusion

The results indicate a strong positive correlation *(r)* of 0.99 across all water samples in the irrigation district, highlighting a "*very high"* degree of relationship between EC and TDS, where the presence of ions in the water affects its electrical conductivity either linearly or otherwise. Although there are references to linear and curvilinear relationships between EC and TDS in the literature, the EC and TDS relationships of different water sources in the study area were found to be linear. The K factor, obtained as the constant of proportionality between TDS and EC, fell within the literature range of 400-800 $mg\ l^{-1}\ (dS\ m^{-1})^{-1}$, indicating that water is suitable for irrigation in the AID district. The range of K values also supports the linear relationship between TDS and EC, with high EC values corresponding to high K values, further demonstrating the strong positive correlation between these two factors. Groundwater samples (L8) and drainage effluents in DO2 and DO3 had the highest TDS and EC values as expected, but the K factor was below 700 $mg\ l^{-1}\ (dS\ m^{-1})^{-1}$, which is within the limits of natural water K value, indicating that the water was of suitable quality for irrigation. However, further analysis is necessary at these locations to determine which ion is most prevalent in the water and its correlation with both TDS and EC. The high TDS values in groundwater can also be attributed to continuous agricultural activities and high evapotranspiration rates in the area, which affect its spatial variability. The K value of water samples collected at site L6 was the highest, at 996 $mg\ l^{-1}\ (dS\ m^{-1})^{-1}$, exceeding the acceptable range for irrigation, although it was the primary source of irrigation water for the AID. Because L6 water is sourced from the Seyhan River, the water quality of the river requires continuous monitoring. However, the use of small volumes of water samples for TDS determination at this site may account for this discrepancy in K at this site. Finally, the proposed equations can be generalized for use in situations where measuring TDS is difficult, by relying on the EC values for various water sources in the Lower Seyhan Plain of Turkiye or regions similar to the study area in the Mediterranean region of the world. Furthermore, the proposed equations represent the general characteristics of the mean EC and TDS values over the course of a year. However, future analyses of EC and TDS should be conducted to determine whether the relationship between EC and TDS at each water location remains consistent and whether various factors influence water quality. For short-term or seasonal studies, this analysis should be repeated to derive new equations that express the relationship between EC and TDS for specific periods, such as the winter (rainy) season or the summer (irrigation) season. In future analyses, the volume of water samples should be at least 100 ml, as recommended by Atekwana et al. (2004), to achieve more accurate results for water quality assessments.

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