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Investigation of the Relationship Between Water Quality and Hydrological Drought in Selected River Basins of Türkiye

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This study investigates the relationship between hydrological drought and agricultural irrigation water quality in selected river basins of Türkiye. Long-term streamflow and water quality data from eight stations in the Meriç, Sakarya, Yeşilırmak, Susurluk, and Gediz basins were analyzed. Irrigation water quality was assessed using the Sodium Adsorption Ratio (SAR), sodium percentage (Na%), and the Canadian Water Quality Index (CCME-WQI), while hydrological drought was represented by the Streamflow Drought Index (SDI). Normality tests showed that SDI and Na% were normally distributed at six stations, and SAR at five stations, whereas CCME-WQI did not meet normality at five stations. Correlation and Mann-Whitney U test results indicated no significant relationships between SDI and water quality indices at most stations ($p > 0.05$), while significant localized correlations were identified at specific monitoring points ($p = 0.03$). However, significant differences were found between SDI and CCME-WQI at two stations in the Yeşilırmak Basin ($p < 0.05$). Overall, the results show that hydrological drought exhibits a highly complex and basin-specific character in its effects on irrigation water quality. Trend analysis using the Seasonal Mann-Kendall (SMK) test and Sen's slope method reveals significant temporal variations in the Yeşilırmak Basin. Particularly at the Sütlüce station, the decreasing trend in CCME-WQI continues, according to the records observed in the SDI. This suggests the possibility of adverse deterioration in water conditions due to increased surface variations during rainy periods from a hydrological perspective. Ultimately, this strongly points to innovative, multi-indexed strategies in water resource assessments and long-term trend products.

Keywords: Agricultural irrigation water quality, drought index, SAR, Na%, CCME-WQI, SDI

INTRODUCTION

Changes in the hydrological cycle due to climate change are leading to more severe droughts, which not only reduce water availability but also deteriorate water quality by increasing the concentration of ions and minerals. During drought periods, the dilution capacity of water decreases, causing dissolved substances to become more concentrated, thereby increasing salinity and sodium hazards and reducing the suitability of water for agricultural irrigation. However, the effects of drought on water quality may vary depending on basin-specific conditions and can lead to different outcomes.

The water quality of rivers is shaped not only by natural processes but also by the direct pressures of human activities, such as industrial and urban development. In particular, wastewater discharges agricultural activities, through the use of fertilizers and pesticides, disrupt the nutrient balance of the water, triggering the risk of eutrophication and resulting in widespread pollution.

Water quality indices facilitate analysis processes with a comprehensive method that reduces numerous data points to a single numerical result. While parameters such as SAR and Na% are used in irrigation water activities, the use of combined indices allows for a much more comprehensive and understandable analysis of complex environmental interactions.

Sodium adsorption ratio (SAR) and sodium percentage (Na%) affect soil permeability and aeration by dispersing soil particles. High sodium levels can also influence the solubility of nutrients such as PO_4 through pH shifts. Additionally, EC serves as an indicator of total salinity and osmotic stress, while the presence of Cl ions can cause direct toxicity in sensitive plants. The concentration of these ions and dissolved oxygen (DO) levels are highly important for maintaining the chemical balance of the river system, especially during

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periods of low flow. Therefore, understanding the interactions between these parameters is beneficial for assessing the long-term sustainability of agricultural irrigation under varying hydrological conditions.

Data obtained in previous studies show that parameters such as SAR, Na%, and EC indicate a low sodium risk, but salinity increases when water levels decrease. These findings, consistent with international studies, show that sodium-related values exhibit a more stable graph, while salinity parameters demonstrate a drought-sensitive structure.

Hydrological drought is generally assessed using flow-based indicators, and the SDI index allows for analysis across multiple time scales. Thus, the impact of drought on water quality is complex and basin-specific, highlighting the need for multi-parameter approaches. Previous studies, particularly in Türkiye, have generally addressed water quality, irrigation, and hydrological drought separately; those in Türkiye are often limited to a single basin or a few parameters (Çelebi and Özdemir, 2015; Demir *et al.*, 2016; Er *et al.*, 2023; Demir *et al.*, 2024). Therefore, the international literature increasingly aims to highlight multi-index approaches (Mosley, 2015; Gao *et al*., 2016; Van Vliet *et al*., 2017).

This study examines the relationship between hydrological drought and irrigation water quality in five major basins in Turkey; it evaluates the data using SDI, SAR, Na%, and CCME-WQI methods with normality tests, non-parametric comparisons, and correlation analyses. The unique aspect of the study is that it considers the drought index together with single and multi-parameter water quality indicators, analyzing complex basin-specific dynamics in an integrated statistical dimension. In this respect, it contributes to multi-basin scale assessments, which are lacking in the literature.

In this study, the primary hypothesis is centered on the interaction between hydrological drought and irrigation water quality. Specifically, the null hypothesis (H_0) assumes that there is no significant impact of streamflow drought (as measured by SDI) on water quality parameters (SAR, Na%, and CCME WQI) across the studied basins. Conversely, the alternative hypothesis (H_1) posits that hydrological drought conditions significantly influence water quality characteristics. Furthermore, due to the complex nature of river systems and the diverse anthropogenic pressures in the Turkish basins, a highly variable and complex relationship is observed between the drought index and water quality variables. This assumption justifies the use of non-parametric statistical methods, such as the Mann-Whitney U test, to capture the potential shifts in water quality during dry and wet periods.

MATERIALS AND METHODS

***Study Area*:** This study was conducted to evaluate the relationship between hydrological drought and irrigation water quality in Türkiye's river basins under varying hydroclimatic, geomorphological, and land conditions. The spatial representation and map visualization of the study area are shown in Figure 1 using QGIS 3.x software.



Figure 1. Locations of the study basins and sampling stations in Türkiye.

In this study, SDI values were calculated using streamflow data from all rivers between 1970 and 2000 years. During the generation and evaluation of SAR, Na%, and CCME water quality index results, only the common months with available observations for all indices between 1983 and 1984 were considered. Accordingly, 9 months for the Suakacağı station, 16 months for the Doğançay station, 23 months for Yenice, 9 months for the Uzunköprü station, 11 months for the Baklacı station, 22 months for Sütlüce, 22 months for Durucasu HES, and 9 months for Yahyaköy were used. The WQI values corresponding to these selected months were evaluated together with the SDI values of the same months. While streamflow data at this station were measured on a daily basis, water quality data were measured once per month.

Table 1. Hydrological and physical characteristics of the studied river basins and monitoring stations.

Basin	Main River / Stream	Monitoring Station	Catchment Area (km^2)	Mainstream Length (km)
Meriç	Ergene River	Uzunköprü	~11,325	~281
Meriç	Tunca River	Suakacağı	~14,500*	~61 (in Türkiye)
Sakarya	Sakarya River	Doğançay	~58,160	~824
Sakarya	Sakarya River	Yenice (Nallıhan)	~58,160	~824
Yeşilırmak	Yeşilırmak River	Durucasu (HEPP)	~36,114	~519
Yeşilırmak	Yeşilırmak River	Sütlüce	~36,114	~519
Susurluk	Simav Stream	Yahyaköy	~22,399	~321
Gediz	Alaşehir Stream	Baklacı	~18,000	~401

Source: SHW (State Hydraulic Works). (2022).

*The area specified for the Tunca River represents the region within the drainage basin and watershed system at the Turkish border.

Within the Meriç Basin, the Uzunköprü section of the Ergene River and the Suakacağı section of the Tunca River were examined. Located in the Thrace Region of northwestern Türkiye, the basin consists of a low-slope topography and extensive alluvial plains. The Ergene River is present in areas with intensive industry and agriculture, leading to water quality deterioration. The Uzunköprü section, near its confluence with the Meriç River, represents a critical area for evaluating drought-water quality interactions and transboundary water management.

The Sakarya Basin is represented by the Doğançay and Yenice (Nallıhan) sections of the Sakarya River. One of Türkiye's largest basins, the Yeşilırmak Basin has high flow rates in spring and low flow rates in summer. These low flow rate conditions reduce dilution capacity and exacerbate the effects of drought on water quality parameters (Çelebi and Özdemir, 2015).

In the Yeşilırmak Basin, the Durucasu Hydroelectric Power Plant section and the Sütlüce section were selected, where summer drought significantly reduces flow and increases pressure on water quality. In the Susurluk Basin, the Yahyaköy section of the Simav Stream, where agricultural activities and climatic conditions strongly affect irrigation water quality, was examined.

In the Gediz Basin, the Baklacı section of the Alaşehir Stream was studied; intensive agriculture, domestic and geothermal discharges, especially under drought conditions, have a significant impact on water quality (Gürsoy Haksevenler and Ayaz, 2021).

In total, eight different stations were selected to represent various hydroclimatic conditions, human-induced pressures, and flow regimes in major river basins across Turkey; thus, it was possible to evaluate drought-water quality relationships.

***Methods*:** This study evaluates the relationship between hydrological drought and agricultural irrigation water quality in some river basins in Türkiye between 1970 and 2000. Irrigation water quality was assessed using SAR, Na%, and CCME-WQI, while hydrological drought conditions were compared using SDI. While investigating the correlation relationship, the water quality index value corresponding to the same month in which the monthly SDI was calculated was used in the analysis. CCME-WQI was calculated using five physicochemical parameters: pH, EC, DO, PO_4, and Cl. Statistical analyses included descriptive statistics, Shapiro-Wilk normality test, correlation analysis (Pearson and Spearman), and Mann-Whitney U test when examining the relationships between drought and water quality parameters. The selected indicators and parameters are used in irrigation water quality assessment and drought analysis (Richards, 1954; Ayers and Westcot, 1985; CCME, 2001).

The 1970-2000 period was selected as a reference interval to examine the relationship between drought and water quality in a relatively undisturbed 'natural laboratory' setting. This choice avoids the masking effects of recent intensified human interventions, such as dam construction and intensive irrigation, which have become more prevalent after 2000. Data were sourced from the General Directorate of State Hydraulic Works (SHW), ensuring high reliability through official monitoring protocols. All water quality parameters were analyzed in accredited laboratories using standard methods in accordance with APHA (American Public Health Association) standards for the examination of water and wastewater, which ensures the minimization of data uncertainty and high reproducibility of the measurements.

The guideline values used in the CCME-WQI calculation are primarily based on FAO irrigation water quality standards (Ayers and Westcot, 1985). For parameters not included in the FAO guidelines (DO and PO_4), threshold values were taken from the Canadian Water Quality Guidelines (CCME, 2001) to ensure methodological consistency. The dataset was obtained by the SHW and the Ministry of Agriculture and Forestry of Türkiye.

Table 2. Water quality parameters, threshold values, and references used in the CCME-WQI calculation.

Parameter		Guideline value	Reference
pH	-	6.5-8.4	Ayers and Westcot, 1985
EC	µS/cm	≤700 (no restriction	Ayers and Westcot, 1985
DO	mg/L	≥ 5.5	CCME, 2001
PO_4	mg/L	≤ 0.1	CCME, 2001
Cl	mg/L	< 140 (sensitive crops)	Ayers and Westcot, 1985
		140 - 350 (moderately sensitive)	
		350 - 700 (moderately tolerant)	

Note: For CCME-WQI calculation, ≤700 µS/cm was adopted as the objective value to represent the upper limit for 'no restriction' on irrigation use.

***Sodium Adsorption Ratio (SAR) and Sodium Percentage (Na%)*:** Ion concentrations were expressed in meq L^{-1} and SAR and Na% values were calculated using standard methods, then evaluated according to the irrigation water quality classification schemes of Richards (1954) and Wilcox (1955).

***Canadian Water Quality Index (CCME WQI)*:** The CCME WQI was selected because it combines multiple parameters (pH, EC, DO, PO_4, Cl) into a single score, accounting for different units and measurement frequencies. The core strength of this index lies in its three-dimensional evaluation approach: Scope (F_1), Frequency (F_2), and Amplitude (F_3). This allows for a granular assessment of water quality by accounting for not only how many guidelines were breached but also how often and to what extent those violations occurred. Such a multi-faceted analysis is essential when investigating the intricate relationship between hydrological drought (SDI) and river health, as it captures the cumulative environmental pressure that a single-parameter analysis would overlook (Neary *et al.*, 2001). The calculated index

values were classified into quality categories ranging from excellent to poor (Tyagi *et al.*, 2013; Bilgin, 2018).

***Streamflow Drought Index (SDI)*:** The SDI, developed by Nalbantis (2008), was used to determine hydrological drought conditions. SDI calculations were performed using available monthly flow observations for each basin. Thus, the hydrological drought behavior of the basins was evaluated on a monthly basis depending on the measurement conditions. SDI results were performed based on a classification ranging from extremely dry conditions to extremely humid conditions (Nalbantis and Tsakiris 2009).

***Statistical Analyses*:** Descriptive statistics, normality tests, correlation analyses, and group comparison tests were applied to examine the relationships between irrigation water quality indices and hydrological drought conditions. Data distribution was evaluated according to mean, standard deviation, median, minimum, and maximum values. Normality was assessed using the Shapiro-Wilk test (α = 0.05). Pearson correlation was used for normally distributed variables, and Spearman correlation was used when normality was not achieved (Mishra *et al.*, 2019). Differences between drought and normal/wet periods were evaluated using the Mann-Whitney U test for non-normally distributed data (Zar, 2010; Gibbons and Chakraborti, 2011). In addition, Seasonal Mann-Kendall (SMK) trend analysis was applied to determine temporal trends in SDI and CCME-WQI values at the selected stations. Kendall's tau and Sen's Slope statistics were calculated to evaluate the direction and magnitude of the trends (Sen, 1968; Hirsch *et al.*, 1982). Confidence intervals were also estimated to assess the reliability of the correlation coefficients.

RESULTS

The relationship between hydrological drought and irrigation water quality was assessed using SDI, SAR, Na%, and CCME-WQI, supported by statistical and correlation analyses and interpreted based on relevant literature.

Although multiple statistical analyses were performed, the results were interpreted within a hypothesis-driven hydrological framework. Nevertheless, the potential limitation related to Type-I error arising from multiple comparisons should be considered when interpreting the findings.

Figure 2 shows the distribution of SAR, Na%, and CCME-WQI across the eight stations. SAR values remained within the low sodium hazard class (0-10) at all stations, with medians between 0.98 and 1.42. Na% values were generally within the low hazard class (20-40%), although some outliers above 40% were observed at Gediz-Alaşehir and Meriç-

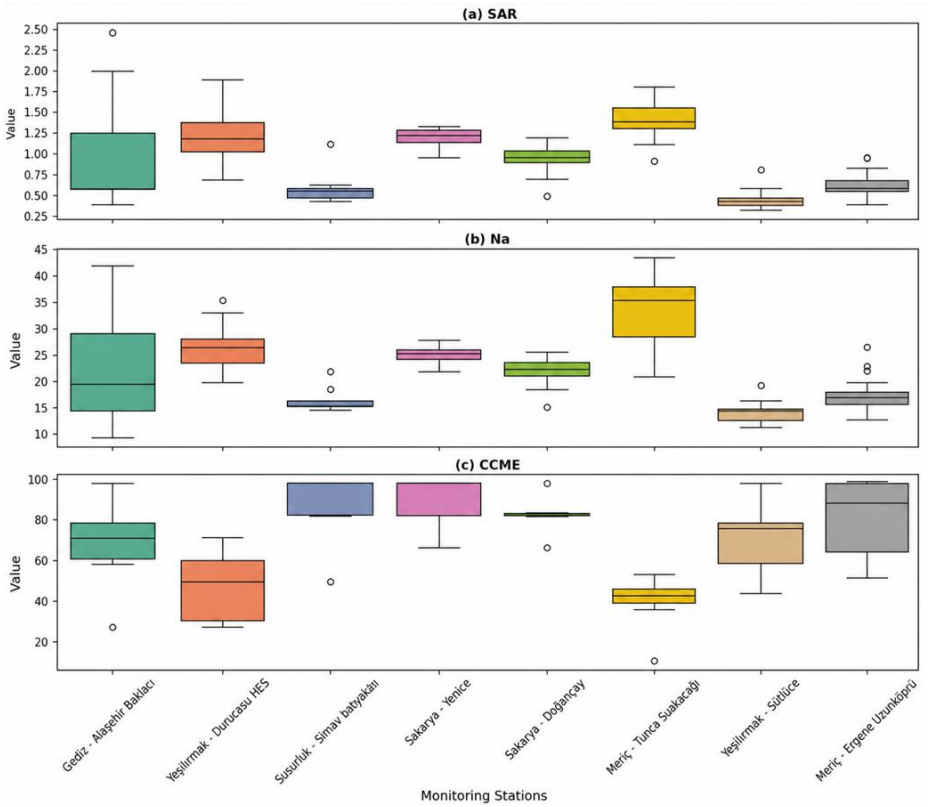


Figure 2. Boxplot distributions of SAR, Na%, and CCME-WQI values across monitoring stations in the study basin.

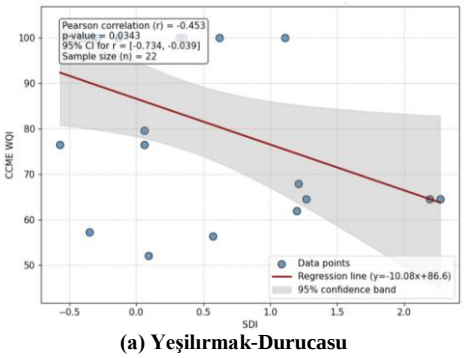
Tunca. CCME-WQI exhibited the widest variability, with low-quality outliers at Yeşilırmak-Durucasu and Meriç-Tunca.

***Results of the Shapiro-Wilk Normality Test*:** Shapiro-Wilk test results reveal that SDI and Na% showed normal distribution in six stations, while SAR showed normal distribution in five stations. In contrast, CCME-WQI did not meet the normality assumption in five stations and showed greater variability compared to single-parameter indices. Similar findings have been reported in previous studies; multi-parameter indices deviate from normality due to decreasing dilution and concentration fluctuations during drought (Kazi *et al*., 2009; Li *et al*., 2020). At the basin scale, all indices showed normal distribution in Meriç Basin stations (Tunca-Suakacağı and Ergene-Uzunköprü), while deviations were more common in Yeşilırmak and Susurluk basins (Varol *et al*., 2013; Demir *et al*., 2016). Overall, SAR, Na%, and SDI showed more stable distributions, while CCME-WQI exhibited higher variability; Therefore, non-parametric tests were applied in cases where the normality condition could not be met.

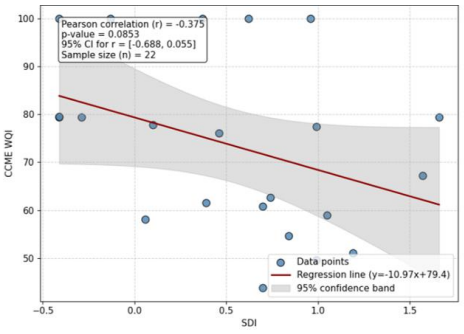
***Results of The Mann-Whitney U Test*:** The Mann-Whitney U test results show that no statistically significant difference was observed between CCME-WQI, SAR, and Na% at most stations ($p > 0.05$). While SDI-SAR and SDI-Na% comparisons were not found to be significant at any station, significant differences were detected in SDI-CCME-WQI at the Durucasu and Sütlüce stations in the Yeşilırmak Basin ($p < 0.05$). This may be due to the multiparameter nature of CCME-WQI, which can show delayed or indirect responses to drought conditions. Similar findings have been made in previous studies (Tyagi *et al*., 2013; Mosley, 2015). Overall, the Mann-Whitney U test results indicate that hydrological drought leads to statistically significant shifts in the distributions of water quality parameters at specific stations.

***Result of the Correlation Analysis*:** Correlation analysis revealed that while there was no uniform significant relationship across the majority of the stations ($p > 0.05$), localized significant correlations were observed at specific points, such as the Sakarya-Yenice and Yeşilırmak-Durucasu stations ($p = 0.03$). Negative correlations between SDI and CCME-WQI in Yahyaköy (Susurluk Basin) and Sütlüce (Yeşilırmak Basin) demonstrate complex and non-monotonic water quality responses to drought. SDI reflects short-term flow variability, while SAR and Na% are controlled for long-term variability (Richards, 1954; Ayers and Westcot, 1985; Apodaca *et al*., 2002). This suggests that the lack of strong correlations is not due to a methodological error, but rather to the complex and non-monotonic nature of the relationship between drought and water quality (Whitehead *et al*., 2009; Mosley, 2015).

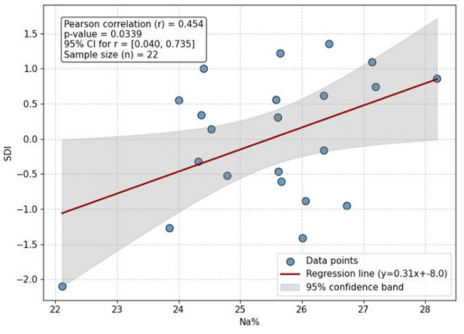
Regression plots for significant correlations are shown with their respective Pearson coefficients (r), p-values and confidence intervals. Figure 3 shows the distribution of these relationships. At the Sakarya-Yenice station (Figure 3c), a significant positive correlation was found between SDI and Na% ($r = 0.45$, $p = 0.03$), indicating that Na% decreased as drought severity increased. At the Yeşilırmak-Durucasu station (Figure 3a), a statistically significant negative trend was observed between SDI and CCME-WQI ($r = -0.45$, $p = 0.03$). A similar negative trend was also observed at the Yeşilırmak-Sütlüce station (Figure 3b) ($r = -0.38$, $p = 0.09$), although it did not reach the standard level of statistical significance. The significant results obtained from the Mann-Whitney U test indicate that the differences between drought and non-drought periods arise from shifts in the data distributions (stochastic dominance) rather than a constant linear or functional relationship.



(a) Yeşilırmak-Durucasu



(b) Yeşilırmak-Sütlüce



(c) Sakarya-Yenice

Figure 3. Scatter plots between SDI and CCME WQI and Na% at (a) Yeşilırmak-Durucasu, (b) Yeşilırmak-Sütlüce and (c) Sakarya-Yenice stations.

Table 3. Seasonal trends in SDI and CCME WQI across selected station

	SDI				CCME			
	P value (α =0.05)	**Kendall's tau**	**Sen's Slope**	**Trend**	**P value (α =0.05)**	**Kendall's tau**	**Sen's Slope**	**Trend**
Sakarya River Doğançay Station	0.04	1 (↑)	1.18	Yes (Increasing)	1.0	0.0	0.0	No
Sakarya River Yenice Station	0.11	0.6 (↑)	0.88	No	1	0.0	-7.85	No
Yeşilırmak River Sütlüce Station	0.027	0.8 (↑)	0.86	Yes (Increasing)	0.004	-1 (↓)	-23	Yes (Decreasing)
Yeşilırmak River Durucasu HES Station	0.34	0.4 (↑)	1.14	No	0.08	-0.6 (↓)	-27.8	No

Non-linear regression models (logarithmic and exponential) were additionally evaluated to investigate potential non-linear hydrological responses reported in the literature (Van Vliet et al., 2023; Mosley, 2015; Schafer et al., 2021). When the coefficients of determination (R^2) were compared, the linear regression model showed the highest explanatory power in the Yeşilırmak-Durucasu station between SDI and CCME indices (Linear: $R^2 = 0.21$; Logarithmic: $R^2 = 0.01$; Exponential: $R^2 = 0.07$). Similarly, in the Sakarya-Yenice station between SDI and Na% indices, the logarithmic model slightly outperformed the linear and exponential models, although all models exhibited relatively similar performances (Linear: $R^2 = 0.21$; Logarithmic: $R^2 = 0.23$; Exponential: $R^2 = 0.19$). In contrast, at the Yeşilırmak-Sütlüce station between SDI and CCME indices, all regression models produced weak relationships, with the exponential model showing comparatively higher explanatory power (Linear: $R^2 = 0.13$; Logarithmic: $R^2 = 0.003$; Exponential: $R^2 = 0.14$).

The comparative assessment of linear and non-linear regression models revealed that the hydrological response of water quality indices to drought conditions differed among stations. In certain river systems, linear models explained the variability more effectively, whereas in others, logarithmic or exponential models produced slightly better fits. These results indicate that drought-water quality relationships are basin-specific and may reflect both linear and non-linear response patterns shaped by local hydrological and environmental conditions. This also highlights the importance of evaluating drought-water quality relationships separately for each basin in future studies.

***Result of the Trend Analysis*:** Specifically for trend analysis, using CCME WQI was considered more appropriate than conducting a salinity-based analysis in order to determine the overall water quality trend. In addition, since trend analysis requires longer-term datasets, the necessary basin and index selections were made accordingly. Seasonal Mann-Kendall (SMK), Kendall's tau and Sen's Slope values was calculated for SDI and CCME in these stations. The trend analysis was performed using the Python programming language (v3.11) within the Google Colaboratory environment. Significant trends were detected at the Yeşilırmak River Sütlüce Station in terms of comparing the relationship between drought and water quality trends. This indicates that water quality may also deteriorate during hydrologically wet periods (Table 3).

DISCUSSION

The results show that the relationship between hydrological drought and irrigation water quality is highly variable and lacks consistency across the studied area. Although an increase in dissolved matter is often expected during drought, no statistically significant relationship was found between SDI and water quality parameters at the majority of the monitoring stations, with the exception of specific locations where localized pressures are dominant. This indicates that the relationship is influenced by basin-dependent factors (Mosley, 2015; Van Vliet *et al*., 2017). Furthermore, water quality is determined not only by short-term changes but also by multiple environmental factors (Qiu *et al*., 2023; Jo *et al*., 2024).

Nalbantis and Tsakiris (2009) noted that existing indices used to determine hydrological drought are in terms of data and calculations, and proposed the Streamflow Drought Index (SDI) as similar to the Standardized Precipitation Index (SPI), which is widely used in meteorological drought. The SDI is based on cumulative streamflow data for 3, 6, 9, and 12 months within the hydrological year. The developed method has been shown to be particularly applicable in basins with limited streamflow data.

While valuable developments in the literature are evident, a large portion of the research is limited to a single basin area or focuses solely on hydrological drought indices (such as SDI). However, there is a noticeable lack of a comparative analysis integrating hydrological drought with multidimensional water quality indices (CCME WQI, SAR, %Na) that cumulatively affect water quality and are critical for overall irrigation management. While current outbreaks generally address the change in individual yield due to drought, the simultaneous evaluation of five different major basins (Meriç, Sakarya, Yeşilırmak, Susurluk, and Gediz) from both drought and multiple water quality classification perspectives constitutes the fundamental uniqueness of this study and fills in the gaps in the existing literature.

Discharging domestic and industrial wastewater into receiving environments without adequate treatment increases the organic matter and pollutant load in rivers, reducing the effectiveness of natural self-treatment processes. The limited carrying capacity of rivers causes these pollutants to be transported to downstream areas, leading to secondary pollution problems in lake and marine ecosystems. In the literature, this process is considered an important indicator that river pollution has a highly complex and cumulative character (Gündoğdu and Turhan, 2004; Kurtulmuş, 2006).

In the Meriç River region, it is stated that pesticide residues negatively affect water quality and put pressure on the ecosystem (Karakaya *et al*., 2018). Agricultural surface runoff increases turbidity, suspended solids, phosphate levels, and the risk of eutrophication in the Meriç River. It has been determined that pollutants are directly transported into the river, especially during rainy periods, through channels carrying agricultural drainage water (Yıldız *et al*., 2016).

Agricultural activities stand out as pressure factors affecting stream water quality, particularly due to their diffuse pollution character. Fertilizers and pesticides used in agricultural production are transported into aquatic environments depending on hydrometeorological conditions; In this study, the negative correlation (r = -0.38) and opposing trends identified at the Yeşilırmak-Sütlüce station suggest that non-point source pollution from agricultural runoff could be a potential factor in this basin, as suggested by the regional land use characteristics. During periods of increased streamflow (higher SDI), rainfall is considered to potentially contribute to the transport of sediment and chemical loads, representing a possible explanation for the observed water quality shifts. This indicates that the increased water volume is insufficient to dilute the pollutants; instead, it actively facilitates the transport of larger pollutant loads, a phenomenon that may be associated with the 'flushing effect' literature, although further event-based monitoring would be required to confirm this specific mechanism. This results in increased nutrient salt concentrations and a higher risk of eutrophication. The literature indicates that this process affects not only water quality parameters but also the structural and functional integrity of aquatic ecosystems (Taşkaya, 2004; Schwarzenbach *et al*., 2010). In this context, the relationship between agricultural production and water quality is considered not only from the perspective of pollution level but also from the perspective of ecosystem resilience.

The basin-specific responses to drought observed in this study are further supported by recent localized research in Türkiye. For instance, Er *et al*. (2023) reported that water quality in the Bingöl irrigation canals remained remarkably stable over a five-year period, with SAR and Na% values showing no significant seasonal variation, which aligns with the stability observed in our Susurluk and Gediz stations. Furthermore, Demir *et al*. (2024) highlighted that in micro-catchments with high erosion risk, such as the Çapakçur Stream, water quality consistently falls into the 'marginal' class due to stable pollutant factors like total suspended solids. These findings reinforce our conclusion that while hydrological drought (SDI) influences flow, the resulting impact on irrigation water quality is heavily moderated by local geological and anthropogenic factors, leading to very variable patterns across different monitoring stations.

The absence of a consistent correlation between SDI and water quality indices indicates that drought impacts vary by basin. Multiple factors (hydrological, geological, anthropogenic) may play a role. Furthermore, the differing behaviors observed at some stations (e.g., Sakarya-Yenice) highlight the crucial role of local conditions and groundwater contribution.

In general, general assumptions about the effects of drought on water quality can be misleading. The reliability of the long-term trends observed in this study is underpinned by the quality of the raw data, which was generated in accredited SHW laboratories under APHA standards. This high-standard data collection process mitigates potential uncertainties, providing a solid baseline for assessing the complex interactions between hydrological drought and water quality. More comprehensive approaches are needed for more accurate assessments and conclusions.

***Conclusions*:** This study evaluated the relationships between hydrological drought and irrigation water quality in different river basins in Türkiye using the SDI, SAR, Na%, and CCME-WQI indices. The results showed no strong or statistically significant relationships between drought severity and water quality indicators.

The findings indicate that hydrological drought and water quality are governed by different processes and temporal scales. While SDI reflects short-term flow variability, SAR and Na% are mainly controlled by geological and hydrogeochemical factors. Similarly, the multi-parameter structure of CCME-WQI may mask drought effects due to the varying responses of individual parameters. Overall, the Mann-Whitney U test confirmed that drought conditions result in significant distributional shifts in water quality indices, though these effects are very basin-specific and do not imply a direct causal or functional relationship.

However, this study has some limitations that should be acknowledged. First, the use of monthly sampling frequencies may not fully capture high-frequency water quality fluctuations triggered by sudden hydrological events (e.g., flushing effects). Second, while the study identifies complex interactions, it does not employ predictive non-linear modeling, which remains a subject for future research. Finally, the findings are station-specific and reflect localized dynamics rather than broad regional generalizations. Despite these limitations, the reliability of the results is underpinned by the quality of the raw data, which was generated in

accredited SHW laboratories following international APHA standards.

From an agricultural perspective, our findings strongly support the idea that there is no 'single truth' or a universal rule for irrigation water management during drought periods. The response of water quality to flow reductions is site-specific and depends heavily on the local geographical and anthropogenic context. Therefore, instead of relying on fixed regional standards, agricultural water management must adopt more location-based strategies. This approach contributes to the existing literature by offering a more comprehensive and process-oriented perspective for sustainable water resource management under changing climatic conditions, emphasizing that future adaptive strategies must prioritize basin-scale sensitivity over generalized national assessments.

***Conflict of Interest*:** Conflict of Interest: The Authors declare that there is no conflict of interest.

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REFERENCES

Apodaca, L.E., D.K. Mueller and B.C. Ruddy. 2002. Water quality in the lower Kansas River Basin, Kansas and Nebraska, 1998-2000. U.S. Geological Survey Water-Resources Investigations Report 02:4179.

Ayers, R.S. and D.W. Westcot. 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29, Food and Agriculture Organization of the United Nations, Rome.

Bilgin, A. 2018. Surface water quality assessment using water quality indices. Environmental Monitoring and Assessment 190:1-15.

CCME. 2001. Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0 user's manual. Winnipeg, MB.

Çelebi, A. and M. Özdemir. 2015. Evaluation of Sakarya River flow regime. Journal of Engineering Sciences 21:45-58.

Demir, V., A. Ünlü and S. Erşahin. 2016. Assessment of irrigation water quality of Murat River (Eastern Turkey). Environmental Monitoring and Assessment 188:1-14.

Demir, Y., H. Er, A.D. Demir and R. Meral. 2024. An evaluation of water quality in micro-catchments with high erosion risk with CCME water quality index: Case of Capakçur microcatchment. Environmental Engineering and Management Journal 23:2353-2363.

Er, H., A. Toprak and M. Atasoy. 2023. Water quality assessment for irrigation canals (Bingöl case study). Thermal Science 27:3299-3311.

Gao, L., Y. Zhang and S. Ding. 2016. Impact of drought on river water quality in a changing climate. Science of the Total Environment 566-567:1022-1031.

Gibbons, J.D. and S. Chakraborti. 2011. Nonparametric statistical inference. 5th ed. Chapman and Hall/CRC, Boca Raton.

Gündoğdu, A. and M. Turhan. 2004. Water pollution and river basin management in Turkey. Environmental Monitoring and Assessment 92:131-145.

Gürsoy Haksevenler, B. and S. Ayaz. 2021. Assessment of agricultural pollution in the Gediz Basin. Environmental Monitoring and Assessment 193:1-15.

Hirsch, R.M., J.R. Slack and R.A. Smith. 1982. Techniques of trend analysis for monthly water quality data. Water Resources Research 18:107-121.

Jo, M., J. Kim and S. Lee. 2024. Impacts of hydrological drought on river water quality under climate variability. Science of the Total Environment 906:167512.

Karakaya, N., S. Akça and Y. Demir. 2018. Deposition of pesticide residues in the Meriç River. Trakya University Journal of Science. 19:55-63.

Kazi, T.G., M.B. Arain, M.K. Jamali, N. Jalbani, H.I. Afridi, R.A. Sarfraz and A.Q. Shah. 2009. Evaluation of water quality of polluted river using multivariate statistical techniques. Ecotoxicology and Environmental Safety. 72:301-309.

Kurtulmuş, F. 2006. Water pollution and its environmental effects. Nobel Publishing and Distribution, Ankara.

Li, S., Q. Zhang and Z. Xu. 2020. Spatial and temporal variation of river water quality under drought conditions. Journal of Hydrology 584:124698.

Mishra, P., U. Singh, C.M. Pandey, P. Mishra and G. Pandey. 2019. Application of Shapiro-Wilk test for normality assessment. Annals of Cardiac Anaesthesia 22:67-72.

Mosley, L.M. 2015. Drought impacts on the water quality of freshwater systems: review and integration. Earth-Science Reviews 140:203-214.

Nalbantis, I. 2008. Evaluation of hydrological drought indices. European Water 23-24:67-77.

Nalbantis, I. and G. Tsakiris. 2009. Assessment of hydrological drought revisited. Water Resources Management 23:881-889.

Neary, B.P., H. Leach and M.G. Dyer. 2001. Application and testing of the Canadian Council of Ministers of the Environment Water Quality Index for assessing water quality in British Columbia. Water Quality Research Journal of Canada 36:519-536.

Qiu, J., X. Wang, Y. Li, H. Zhang and Z. Liu. 2023. Effects of hydrological drought on river water chemistry. Journal of Hydrology 620:129376.

Richards, L.A. 1954. Diagnosis and improvement of saline and alkaline soils. USDA Handbook No. 60, Washington, DC.

Schafer, B., C.M. Heppell, H. Rhys and C. Beck. 2021. Fluctuations of water quality time series in rivers follow superstatistics. iScience 24:102881

Sen, P.K. 1968. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association 63:1379-1389.

Schwarzenbach, R.P., B.I. Escher, K. Fenner, T.B. Hofstetter, C.A. Johnson, U. von Gunten and B. Wehrli. 2010. The challenge of micropollutants in water systems. Science. 313:1072-1077.

State Hydraulics Work (SHW). 2022. Annual Activity Report 2022. Ankara, Türkiye.

General Directorate of Water Management (GDWM). 2022. Annual Activity Report 2022. Ankara, Türkiye.

Taşkaya, A. 2004. Water pollution and control. Nobel Publishing, Ankara.

Tyagi, S., B. Sharma, P. Singh and R. Dobhal. 2013. Water quality assessment using water quality index. Environmental Monitoring and Assessment 185:1-17.

Van Vliet, M.T.H., F. Ludwig, J.J.G. Zwolsman, G.P. Weedon and P. Kabat. 2017. Global river discharge and water temperature under climate change. Environmental Research Letters 12:024005.

Van Vliet, M.T.H., J. Thorslund, M. Strokal, N. Hofstra, M. Flörke, H. Ehalt Macedo, A. Nkawasa, T. Tang, S.S. Kaushal, R. Kumar, A. van Griensven, R. Bouwman and L.M. Mosley. 2023. Global river water quality under climate change and hydroclimatic extremes. Nature Reviews Earth and Environment 4:687-702.

Varol, M., B. Gökot and A. Bekleyen. 2013. Dissolved heavy metals in the Tigris River (Turkey): spatial and temporal variations. Environmental Science and Pollution Research 20:6096-6108.

Yıldız, D., C. Sağlam and Ç. Güler. 2016. Seasonal variation of physical water quality parameters of Kızılırmak River. Journal of Water Sciences and Technology 7:33-44.

Whitehead, P.G., R.L. Wilby, R.W. Battarbee, M. Kernan and A.J. Wade. 2009. Potential impacts of climate change on water quality. Hydrological Sciences Journal 54:101-123.

Wilcox, L.V. 1955. Classification and use of irrigation waters. USDA Circular No. 969, Washington, DC.

Zar, J.H. (2010) Biostatistical Analysis. 5th Edition, Prentice-Hall/Pearson, Upper Saddle River, xiii, Pp.944.

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