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Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi 2024; 10 (3): 253-266 Araştırma Makalesi/Research Article

Yarı Kurak Havzalardaki Düşük Akışların Analizi: Söğütözü ve Terme Çayı Örnekleri

Semih EDİŞ[1*], Ceyhun GÖL[1], Yusuf SERENGİL[2]

[1] Çankırı Karatekin Üniversitesi, Orman Fakültesi, Orman Mühendisliği Bölümü, Çankırı/Türkiye
[2] İstanbul Üniversitesi-Cerrahpaşa, Orman Fakültesi, Orman Mühendisliği Bölümü, İstanbul/Türkiye
[*]**E-mail:** semihedis@karatekin.edu.tr

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Öz

Bu çalışmanın amacı, Çankırı ilinin Söğütözü ve Terme Çayı Havzalarında kurak mevsim boyunca meydana gelen düşük akışların fiziksel, kimyasal ve hidrolojik özelliklerini analiz etmek ve bu havzalardaki su kalitesi ile akış arasındaki ilişkiyi tespit etmektir. Çalışmanın amacı, havza özelliklerini inceleyerek, su kalitesini değerlendirerek ve eğilimleri analiz ederek düşük nehir akışlarının nedenlerini ve etkilerini açıklığa kavuşturmaktır. Kurak mevsimdeki düşük nehir akışları, kaynak kullanımı ve ekosistem sağlığı için hayati önem taşımaktadır. Bunu başarmak için, her iki havzada 1967'den 2010'a kadar 43 yıllık bir süre boyunca toplanan günlük ortalama akış verileri kullanılarak ilk düşük akış hesaplamaları yapılmıştır. Su örneklemesi, bu havzalarda kaydedilen düşük akışlara denk gelecek şekilde, Nisan-Aralık ayları arasında haftalık olarak aynı gün ve aynı saatte gerçekleştirilmiştir. Ayrıca, yıllık düşük akış endeksi değerlerinde bir eğilim olup olmadığını belirlemek için bir analiz yapılmıştır. Çalışma dönemi boyunca 35 su numunesi 18 parametre açısından hem fiziksel hem de kimyasal olarak analiz edilerek düşük akış ve su kalitesi arasındaki korelasyon tespit edilmiştir. Sonuç olarak, Söğütözü Deresi havzasında dere akışı ile fenolftalein alkalinitesi, toplam sertlik, kalsiyum sertliği, organik madde, amonyum, bulanıklık, pH, elektriksel iletkenlik ve tuz arasında; Terme Deresi havzasında ise dere akışı ile metiloranj alkalinitesi, toplam sertlik, magnezyum sertliği, klorür, sodyum, bulanıklık, elektriksel iletkenlik ve tuz arasında anlamlı bir korelasyon olduğu tespit edilmiştir. Düşük akış hesaplamalarında kullanılan beş endeks (Q95, Q90, Q75, Q50 ve 7Q1) arasında yalnızca Q95 Akış Endeksi için kayda değer bir eğilim gözlenmiştir.

Analysis of Low Flows in Semi-Arid Watersheds: Söğütözü and Terme Creek Cases

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Abstract

This study aims to analyze the physical, chemical, and hydrological characteristics of low flows in the Söğütözü and Terme Creek Watersheds of Çankırı province during the dry season, and to ascertain the relationship between water quality and flow in these watersheds. The goal of the study is to clarify the causes and effects of low river flows by examining watershed characteristics, assessing water quality, and analyzing trends. Low river flows during the dry season are vital for resource utilization and ecosystem health. To achieve this, initial low flow calculations were performed using daily average flow data collected over 43 years, from 1967 to 2010, in both watersheds. Water sampling was conducted weekly on the same day and at the same time during the period from April to December, coinciding with the recorded low flows in these watersheds. Furthermore, an analysis was conducted to determine if a trend existed in the annual low flow index values. During the study period, 35 water samples were analyzed both physically and chemically for 18 parameters to ascertain the correlation between low streamflow and water quality. Consequently, it was determined that a significant correlation existed between streamflow and phenolphthalein alkalinity, total hardness, calcium hardness, organic matter, ammonium, turbidity, pH, electrical conductivity, and salt in the Söğütözü Creek watershed; as well as between streamflow and methyl orange alkalinity, total hardness, magnesium hardness, chloride, sodium, turbidity, electrical conductivity, and salt in the Terme Creek watershed. A notable trend was observed solely for the Q95 Flow Index among the five indices utilized in low flow calculations (Q95, Q90, Q75, Q50, and 7Q1).

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INTRODUCTION

The effects of climate variability on water resources are significant, as excessive precipitation can cause floods, while insufficient rainfall combined with high temperatures can lead to droughts (IPCC, 2021). Temporal climate alterations have adversely impacted water resources. Floods arise from abrupt and excessive precipitation, whereas droughts manifest due to insufficient rainfall and high temperatures. Drought, defined as a temporary imbalance in regional moisture relative to water scarcity, is a natural climatic phenomenon. Hydrological drought, resulting from extended meteorological drought, is evident in the elements of the hydrological system, including sustained precipitation deficits, surface runoff, and soil moisture (Usul, 2008). The disruption in the precipitation pattern, ineffective water utilization, and rising demands escalate the daily requirement for water. This demand escalates further during arid periods and in arid regions (Gleick et al., 2020; Yıldırımer and Özalp, 2024).

In arid conditions, stream water levels diminish. Particularly in semi-arid regions, a reduction in streamflow results in heightened pollution concentration and harm to the aquatic ecosystem (Kara and Çömlekçioğlu, 2004). The characteristics of the watershed directly influence the attributes of stream water during these periods (Lee et al., 2005). The existing land use conditions within the watershed have both beneficial and detrimental effects on water quality (Bhatti and Latif, 2009). Browne (2003) asserted that the geological structure of the watershed is a primary factor influencing both the quantity and quality of water.

Hydrology and ecology must work closely in semi-arid regions where human activities significantly impact (Pataki et al. 2011; Yıldırımer and Demirci, 2017). In semi-arid regions, particularly those affected by human activity, considerable uncertainties emerge regarding the water budget and the quality of water necessary for the ecosystem. In areas with limited forest coverage, the optimal utilization of the scarce water resulting from precipitation is crucial. Variability in precipitation patterns due to climate change may diminish water availability in ecosystems vulnerable to competition (Yaseef et al., 2010). Ecohydrology, which combines hydrological and ecological perspectives, has started to examine hydrological factors essential for ecosystem sustainability, highlighting the significance of riparian ecosystems in watershed ecohydrology (Zhou et al., 2019). The significance of riparian ecosystems for watershed ecohydrology is growing. Nutrient and nitrogen cycling in these ecosystems may exhibit greater sensitivity compared to other ecosystems (Burt et al., 2010). Elevations in nitrate, nitrite, and ammonium, constituents of the nitrogen cycle, can present substantial risks to aquatic ecosystems and human health. The proliferation of these elements contaminates water and adversely impacts species diversity, abundance, and habitats of organisms such as algae and macroinvertebrates, which are integral components of the aquatic ecosystem (Kalyoncu et al., 2004; Kalyoncu et al., 2008; Türkmen and Kazancı, 2008). Organisms in these delicate ecosystems, which are profoundly influenced by water quality, have recently been utilized as bioindicators for assessing water quality parameters (EPA, 2003; Barbour et al., 2006; Hughes et al., 2009).

Aquatic organisms and riparian vegetation species adapted to arid and semi-arid watersheds endure stress from the progressive reduction of water in the stream during June, July, and August. To maintain the continuity of these ecosystems, a minimum critical flow value, referred to as life water or minimum streamflow, is essential for the stream. Low flows during arid periods are significantly important (Smathkin, 2001). Various indices are employed across different nations to assess the environmental consequences of low flows (Tharme, 2003;Fleig, 2004; Pyrce, 2004). Tennant (1976) proposed a method for calculating the minimum streamflow necessary to sustain the river's health, which is a fundamental hydrological calculation. Subsequent years saw the development of hydrological methods, hydraulic assessment, habitat assessment (simulation), and holistic approaches for calculating low flows (Tannan, 1976; Zappia and Hayes, 1998; Pyrce, 2004; Fetter Jr., 2007; Ryu et al., 2011). Comprehending the attributes of low flows is crucial in various domains beyond the regulation of water quality (Mijuskovic-Svetinovic and Maricic, 2008). Consequently, statistical and geostatistical techniques have been devised to estimate flow in watersheds lacking flow monitoring stations (Castiglioni et al., 2009; Castiglioni et al., 2010). Furthermore, certain researchers have formulated regression models to estimate daily low flows, proposing that these models will facilitate the resolution of various issues in low flow estimation (Sefe, 2006; Mamun et al., 2009).

This study examined the correlation between streamflow and water quality parameters from April to July in the Söğütözü Creek and Terme Creek watersheds of Çankırı province, Turkey, characterized by a semi-arid climate. The analysis of the data revealed the impact of low flows on water quality. Therefore, our findings may trigger other studies on low flows and water quality in Turkey.

MATERIAL AND METHOD

Study Area

The Söğütözü Creek and Terme Creek watersheds, designated as the research area, are situated in Çankırı province within the Central Anatolia Region. Söğütözü Creek and Terme Creek are sub-watersheds of the Kızılırmak Basin (Figure 1).

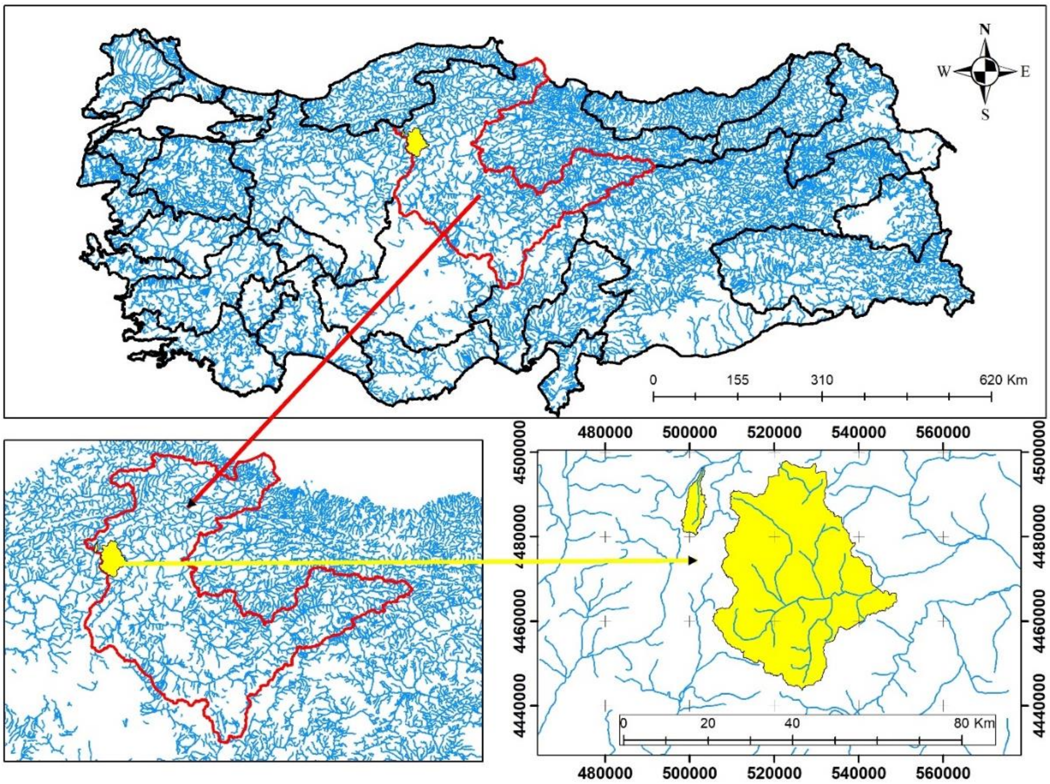

Figure 1. Location map of the research area

The Söğütözü creek watershed has an annual average temperature of 8°C, with January being the coldest month at -2.5°C and July the hottest month at 18.4°C. The annual precipitation is 394.1 mm. Precipitation peaks in May and diminishes until September. May experiences the highest precipitation at 63.0 mm, while September records the lowest at 17.7 mm. The mean annual relative humidity is 64%. The annual precipitation in the Terme Creek watershed amounts to 389.1 mm. May registers the highest precipitation at 49.0 mm, whereas September records the lowest at 14.8 mm. The mean annual temperature is 10.3°C, with January as the coldest month at -2.0°C and July as the hottest at 21.7°C. The mean annual relative humidity is 66% (MGM, 2011).

The Söğütözü Creek Watershed comprises volcanic and pyroclastic rocks (Türkmenoğlu et al., 1991; Akyürek et al. 1980) whereas the Terme Creek watershed displays significant geological diversity with intricate rock formations spanning from the Triassic to the Quaternary period (Akyürek et al., 1980; Şengüler, 2007). The Söğütözü Creek watershed features brown, calcareous brown, and colluvial soils, whereas the Terme Creek watershed is distinguished by brown and alluvial soils, exhibiting localized groundwater issues (Anonymous, 1974).

The Söğütözü Creek and Terme Creek watersheds are situated within the Iranian-Turanian flora zone, characterized by forests, meadows, and aquatic plants in the Söğütözü Creek Watershed, whereas the Terme Creek watershed predominantly features pasture and steppe vegetation (Öner et al., 2010).

Method

The research was executed in four stages: office (initial preparation for field studies), field (collection of water samples and on-site analyses), laboratory (analysis of water samples), and final office (statistical evaluation) studies (Figure 2).

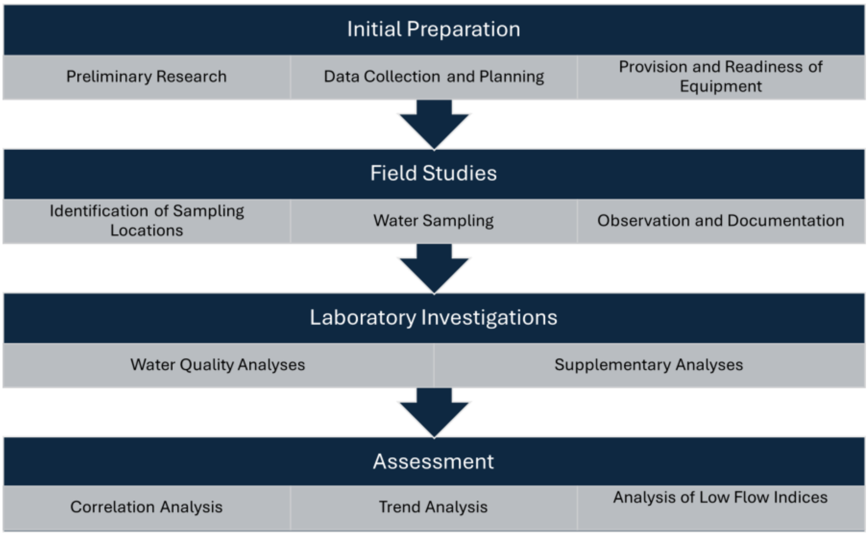

Figure 2. Flowchart of the methodology used in the study

Initial preparation

Before initiating field studies, maps from multiple organizations were acquired to delineate the study watersheds, specifically the Söğütözü Creek watershed and Terme Creek watershed, which are the monitoring stations (15-098 Yuva Station and 15-133 Tüney Station) of General Directorate of Hydraulic Works (DSI). The maps were digitized with ArcInfo 9.3.1 software, and ArcHydro was employed to delineate the drainage characteristics of the watersheds. The frequency of collecting water samples from the streams at the monitoring stations was determined based on data assessments.

Field studies

Research was conducted in the watersheds identified through preliminary data gathered from office studies and their analysis. Water samples were collected from the research areas from April 2011 to December of the same year. The data from previous years were assessed weekly, biweekly, and monthly using the t-test in the SPSS 15.0 software package. The t-test revealed that the water sampling frequency for both watersheds is weekly ($p<0.05$). Water samples were collected on the same day and at the same time to minimize the impact of solar incidence angle and the shading effects of riparian vegetation on all samples. Water samples were collected from the streams utilizing the depth integration method. This method involves lowering the container for the water sample from the surface to the bottom at a constant velocity, to obtain an average concentration from the entire section (Teker, 1985). pH, temperature, electrical conductivity, salinity, dissolved oxygen, and turbidity were measured in situ using portable instruments (Clesceri et. al., 1998).

Laboratory works

Field-collected water samples were subjected to analysis for alkalinity (2320-B titration method), total hardness (2340-C EDTA titrimetric method), calcium (3500-Ca-B method), magnesium (3500-Mg-B method), chloride (4500-Cl-B argentometric method), organic matter (4500-O D method), orthophosphate (4500-P-G method), sodium (3500-Na-B Flame Emission Photometric method), potassium (3500-K-B Flame Photometric method), ammonium (4500-NH4-D ammonium ion selective electrode method), and nitrate (4500-NO3-B method) (Clesceri et al. 1998).

Statistical assessment

This study employed Pearson correlation analysis to determine the statistical relationships between different water quality parameters and streamflow. The SPSS 15.0 software was utilized to acquire all statistical data. The non-parametric Mann-Kendall test was used to analyze trends in annual average flows of the Söğütözü and Terme Creek watersheds. This test was chosen for short, irregular, and skewed observation series because it is independent of random variable distribution and parameters (Yue and Wang, 2004; Cebe, 2007). Assessment of the environmental impact of flow levels from observation stations and the standardization of water quality typically involves the application of hydrological, hydraulic, habitat, and holistic methodologies (Pyrce, 2004; Davie, 2008). This research employed the hydrological indices Q95, Q90, Q75, Q50, and 7Q1 for analysis.

RESULTS AND DISCUSSION

Hydrochemical characteristics of low flows

The measurements conducted between April and December in the research area indicated that the streamflow follows the precipitation pattern. Historically, precipitation in both regions' peaks at the end of April and declines to its lowest level in July. The peak streamflow in Söğütözü Creek watershed was recorded as 0.550 m³/sec, while the peak streamflow in Terme Creek watershed was 5.860 m³/sec. In both watersheds, river flow reaches its lowest level in July. The minimum streamflow in the Söğütözü Creek watershed was 0.03 m³/sec, while in the Terme Creek watershed, it was 0.18 m³/sec (Table 1 and Table 2). The descriptive statistics of the water quality parameters measured in the Söğütözü and Terme Creek watersheds are presented in Table 1 and Table 2, respectively. In the Söğütözü Creek watershed, there was a general increase in pH from April to July and naturally as the dry period progresses. On the contrary, pH, which shows a variable structure over time in the Terme Creek watershed, has generally increased or decreased in the same direction as the streamflow. The effect of precipitation, snowmelt and temperature affect the reaction (pH) of the stream. The temperature of surface waters fluctuated based on geographical location, altitude, season, time of day, river streamflow, depth, and the attributes of pollutants from contaminating sources. In both watersheds, water temperature attained its minimum in December and its maximum in July. The temperature of water is primarily significant for the organisms inhabiting the stream. Specific water temperature ranges exist within which fish can survive. During the low flow period, significant and abrupt fluctuations in streamflow (± 3ºC variations throughout the day) may endanger aquatic life (Göksu, 2003). The electrical conductivity of water is contingent upon the overall concentration of ions and temperature. As the concentration of electrical ions in water rises with temperature, electrical conductivity correspondingly increases. The electrical conductivity of the surface waters in the streams generally increased throughout the study. An increase in TDS was noted in both watersheds, notwithstanding a general decline in streamflow.

Dissolved oxygen in water is essential for the survival of aquatic organisms and the maintenance of water quality. The concentration of dissolved oxygen is contingent upon various physical conditions, including temperature and salinity. As these two values rise, the concentration of dissolved oxygen diminishes (Davie, 2008). There was a reduction in dissolved oxygen levels in July and August when salinity peaked in both watersheds. Turbidity denotes the concentration of suspended particles in water. Turbidity in Söğütözü Creek was minimum in November (1.2 NTU) and highest in August (69.4 NTU). In Terme Stream, the minimum turbidity level was recorded in November (17 NTU), while the maximum level occurred in June (1800 NTU) as a result of increasing streamflows. The limited extent of forested areas resulted in increased sediment transport due to increasing streamflows. Munsuz and Ünver (1995) asserted that the turbidity of stream water fluctuates following abrupt rainfall, with the clay and dust content of sediment introduced into the water exerting a direct influence on turbidity. Likewise, Susfalk et al. (2008) indicated that turbidity escalates with streamflow, particularly following snowmelt. High turbidity adversely impacts the spawning habitats of fish and the environments of numerous invertebrates within the stream ecosystem. Simultaneously, heightened turbidity frequently signifies the presence of additional phenomena, such as eutrophication and channel erosion, within the ecosystem (Jones et al., 2002). The hydroxide, carbonate, and bicarbonate ions in water comprise its alkalinity. Carbonate alkalinity is assessed using phenolphthalein indicator and typically arises in waters tainted by pollutants, including industrial and mining waste (Davie, 2008). Phenolphthalein alkalinity is detected at a pH of 8.3 or higher (Yalçın and Gürü, 2002). In Söğütözü Creek, phenolphthalein alkalinity attained its minimum value (0 mg/L) in April-May and November-December, while its maximum value (22.5 mg/L) occurred at the end of May. The minimum concentration of 2.5 mg/L was recorded in August and December, while the maximum concentration of 55 mg/L was observed in April. Another component of total alkalinity is attributed to bicarbonate ions and is assessed using the methyl orange indicator. The alkalinity of phenolphthalein and methyl orange in aqueous equilibrium varies with fluctuations in pH levels. As pH diminishes, the equilibrium shifts towards bicarbonate (methyl orange) alkalinity. Methyl orange alkalinity is an alkalinity typically found in natural waters (Yalçın and Gürü, 2002). The alkalinity of methyl orange in Söğütözü Creek was recorded at a minimum of 17.5 mg/L in July and a maximum of 105 mg/L in October. In Terme Stream, the minimum concentration was recorded in April (185 mg/L) and the maximum concentration in August (335 mg/L). The total hardness in the study area exhibited variability throughout the measurement periods. In the Söğütözü, the minimum total hardness was recorded in April at 60.61 mg/L, while the maximum was observed in May at 149.49 mg/L. In the Terme Stream, total hardness was recorded at its lowest in May (218.18 mg/L) and at its highest in October (464.65 mg/L). Calcium hardness exhibited a consistent increase over time in the Söğütözü Creek watershed, whereas it initially rose and subsequently declined in the Terme Creek watershed. The calcium hardness in Söğütözü Creek was recorded at a minimum of 28.28 mg/L in April and a maximum of 113.13 mg/L in August. In Terme Stream, the minimum concentration was recorded in September (101.01 mg/L) and the maximum in July (262.63 mg/L). In both watersheds, magnesium hardness demonstrated temporal variability. In the Söğütözü Creek Watershed, magnesium hardness recorded a minimum of 2.02 mg/L in October and November, and a maximum of 86.87 mg/L in September. In the Terme Creek watershed, the lowest concentration was observed in April and May (84.85 mg/L), whereas the highest concentration was noted in September (316.11 mg/L). Chloride is a parameter present in natural waters that signifies the total concentration of salt and can originate from natural minerals or domestic, agricultural, and industrial sources. The chloride concentration was found to be greater in the Terme Creek watershed than in the Söğütözü Creek. In Söğütözü, chloride levels ranged from a minimum of 0.5 mg/L at the end of April to a maximum of 9.5 mg/L in May. In Terme Stream, chloride levels varied from a minimum of 7.0 mg/L in June to a maximum of 52.54 mg/L in July. Dissolved organic matter in water originates from the remains of deceased plants and animals, as well as their metabolic byproducts and excretions. It was determined that organic matter in both watersheds displayed temporal variability. In the Söğütözü Creek Watershed, organic matter concentrations ranged from a minimum of 1.65 mg/L in November to a maximum of 5.33 mg/L in May. In the Terme Creek watershed, a minimum concentration of 0.55 mg/L was documented in April, whereas a maximum concentration of 8.86 mg/L was noted in June. In the Söğütözü Creek watershed, sodium concentrations were at their lowest in July (3.8 mg/L) and peaked in June (49.1 mg/L). In the Terme Creek watershed, the minimum sodium concentration was recorded in June (8.8 mg/L) and the maximum concentration in May (282 mg/L). Potassium can enter streams via groundwater, organic matter from animals and plants, and household waste. In the Söğütözü Creek Watershed, potassium concentrations are at their lowest in July (1.3 mg/L) and peak in May (9.5 mg/L). In the Terme Creek watershed, potassium levels were recorded at a minimum of 2.8 mg/L in April and a maximum of 23 mg/L in May. Serengil et al. (2007) reported in a study conducted in Istanbul that potassium levels increased during the winter months in a watershed characterized by intensive forest land use. It is believed that such a relationship could not develop because most of the watersheds under study are densely populated with agricultural regions. Phosphorus occurs in nature as orthophosphates, polyphosphates, metaphosphates, and ultraphosphates. Orthophosphates exist in aquatic ecosystems and serve as the fundamental components of all organic phosphorus compounds. Orthophosphates enter aquatic systems via agricultural activities, detergents, sewage effluents, and sediment transport (Göksu, 2003; Davie, 2008). In the Söğütözü Creek watershed, orthophosphate concentrations were recorded at a minimum of 0.01 mg/L in July and a maximum of 0.29 mg/L in August. In the Terme Creek watershed, the minimum level was recorded in July (0.07 mg/L) and the maximum level in June (0.54 mg/L). Ammonium is produced directly through the decomposition of proteins or other nitrogenous organic substances by bacteria (Göksu, 2003). As the vegetation period commences, decomposition, particularly along stream banks, significantly elevates ammonium levels (Meynendonckx et al., 2006). In the Söğütözü Creek Watershed, ammonium concentrations attain their lowest levels in July (0.069 mg/L) and their peak in September (0.425 mg/L). In the Terme Creek watershed, a minimum concentration of 0.074 mg/L was recorded in May, while a maximum concentration of 0.303 mg/L was observed in September. Ammonium in ionic form is non-toxic to aquatic organisms, particularly fish. Nevertheless, an increase in ammonium ions can frequently render certain aquatic and terrestrial organisms and drinking water toxic. Frequent elevations in ammonium levels can induce sudden alterations in stream habitats (Jones et al., 2002). Nitrate is the final product of the oxidation of organic nitrogen in natural water bodies. Consequently, the oxidation of nitrogen in the environment depletes dissolved oxygen in aquatic systems (Göksu, 2003). Nitrate is a fundamental nutrient in aquatic ecosystems; however, its excessive presence in water can harm numerous organisms, including humans. In the Söğütözü Creek watershed, nitrate concentration typically rises as streamflow diminishes, whereas in the Terme Creek watershed, nitrate levels fluctuate. In the Söğütözü Creek watershed, nitrate levels were recorded at a minimum of 0.707 mg/L in December and a maximum of 67 mg/L in July. In the Terme Creek watershed, a minimum concentration of 95 mg/L was recorded in November, while a maximum concentration of 189 mg/L was observed in April. Nitrates infiltrate aquatic systems through multiple pathways. The oxidation of ammonia, resulting from the decomposition of proteins in animal and plant residues as well as nitrate fertilizers predominantly utilized in agricultural regions, is the cause (Davie, 2008). The high nitrate levels in the Terme Creek watershed are primarily attributed to the extensive agricultural land within the watershed.

Table 1. Descriptive statistics of water quality parameters of Söğütözü Creek Watershed

	Streamflow (m^3/sec)	Phenolphthalein Alk. (mg/L)	Methyl orange Alk. (mg/L)	Total Hardness (mg/L)	Ca^{+2} (mg/L)	Mg^{+2} (mg/L)	Cl^- (mg/L)	Organic Matter (mg/L)	Orto PO_4^- (mg/L)	NH_4^+ (mg/L)	NO_3^- (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Turbidity (NTU)	pH	Temperature (°C)	Electrical Conductivity	Dissolved O_2 (mg/L)	TDS (mg/L)
count	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
mean	0.15	5.21	76.64	105.69	78.89	25.75	4.5	3.42	0.05	0.15	24.57	10.95	3.43	9.45	8.5	14.25	167.68	9.52	90.84
std	0.12	5.6	16.38	21.85	17.41	20.27	2.15	0.97	0.05	0.09	25.24	8.07	1.33	15.34	0.25	7.82	33.76	1.33	11.37
min	0.03	0	17.5	60.61	28.28	2.02	0.5	1.65	0.01	0.07	0.71	3.8	1.3	1.2	7.92	0.2	98.7	7.56	54.4
25%	0.05	0	70	87.86	71.71	10.1	2.75	2.83	0.03	0.09	2.95	6.85	2.7	3.55	8.37	6.7	143.8	8.65	88.75
50%	0.13	5	82.5	96.97	82.82	22.22	4	3.22	0.04	0.13	9.7	8	3	4.3	8.56	16.1	182	9.07	92.1
75%	0.21	7.5	85	125.25	86.87	39.39	6.5	4.02	0.06	0.17	51	12.15	4	7.57	8.72	20.45	192.2	11.05	96.7
max	0.55	22.5	105	149.49	113.13	86.87	9.5	5.33	0.29	0.43	67	49.1	9.5	69.4	8.79	27.1	215.6	11.7	111.4

Table 2. Descriptive statistics of water quality parameters of Terme Stream Basin

	Streamflow (m^3/sec)	Phenolphthalein Alk. (mg/L	Methyl orange Alk. (mg/L	Total Hardness (mg/L)	Ca^{+2} (mg/L)	Mg^{+2} (mg/L)	Cl^- (mg/L)	Organic Matter (mg/L)	Orto PO_4^- (mg/L)	NH_4^+ (mg/L)	NO_3^- (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Turbidity (NTU)	pH	Temperature (°C)	Electrical Conductivity	Dissolved O_2 (mg/L)	TDS (mg/L)
count	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
mean	1.65	12.50	271.76	366.48	158.80	207.67	21.51	2.62	0.25	0.13	130.74	74.57	4.44	174.63	8.58	16.97	725.86	9.84	406.40
std	1.65	8.77	36.72	52.27	38.13	61.58	10.30	1.73	0.14	0.04	25.91	41.42	3.29	366.93	0.17	6.80	186.42	1.64	78.00
min	0.18	2.50	185.00	218.18	101.01	84.85	7.00	0.55	0.07	0.07	95.00	8.80	2.80	17.00	8.24	5.90	521.00	7.24	273.00
25 %	0.55	8.75	249.00	328.78	138.38	166.16	13.81	1.41	0.13	0.10	110.00	60.90	3.40	42.75	8.45	11.25	574.50	8.77	344.00
50 %	1.05	10.00	282.50	354.54	159.60	210.10	20.99	2.13	0.22	0.12	129.00	66.30	3.90	66.00	8.55	16.80	661.00	9.26	405.00
75 %	2.08	15.00	295.00	407.11	175.76	240.45	25.50	3.37	0.38	0.14	144.50	73.00	4.25	141.50	8.68	21.05	844.00	11.44	445.00
max	5.86	55.00	335.00	464.65	266.66	316.11	52.54	8.86	0.54	0.30	189.00	282.00	23.00	1800.00	8.93	35.60	1251.00	13.28	580.00

Reduced flow conditions markedly influence the properties of surface waters, particularly in semi-arid regions. The impact of low flow on water quality is typically attributed to high pollutant concentrations resulting from diminished water volume. For instance, the elevation of TDS, total nitrogen, and total phosphorus in the Murray River, Australia (Mosley et al., 2012); the rise in chloride, electrical conductivity, and seasonal variability in Germany (Hellwig et al., 2017); alterations in dissolved oxygen and chloride concentration (Hübner & Schwandt, 2018); eutrophication attributed to high phosphorus levels in a semi-arid region of Brazil (Junior et al., 2018; Braga et al., 2015); and algal blooms in New Zealand (Caruso, 2001) exemplify significant studies elucidating this phenomenon. Furthermore, when the impact of human activities is incorporated into the low flow periods in semi-arid regions, analogous results are evident in our research. In California, a semi-arid region in the USA, the issues of phosphorus proliferation and eutrophication emerged due to water extraction from the stream for agricultural purposes during low flow conditions (Ohte and Kendall, 2008).

Statistical analysis of outcomes

The Pearson Correlation Test revealed significant relationships between streamflow and phenolphthalein alkalinity, total hardness, calcium, organic matter, ammonium, turbidity, pH, electrical conductivity, and salinity parameters in the Söğütözü Creek and Terme Creek watersheds. In the Terme Creek watershed, notable correlations were identified between streamflow and methyl orange alkalinity, magnesium, chloride, turbidity, electrical conductivity, and salinity parameters (Table 3).

Table 3. Results of the correlation between water quality parameters and streamflow

Variables		Terme Stream		Söğütözü Creek	
		r	*P*	*r*	*P*
Streamflow (m^3/sec)	Phenolphthalein Alk. (mg/L $CaCO_3$)	0,256	0,138 (Ns)	-0,328	0,045 (*)
	Methyl orange Alk. (mg/L $CaCO_3$)	-0,727	0,000 (**)	-0,284	0,099 (Ns)
	Total Hardness (mg/L)	-0,675	0,000 (**)	-0,338	0,047 (*)
	Ca^{+2} (mg/L)	-0,017	0,924 (Ns)	-0,671	0,000 (**)
	Mg^{+2} (mg/L)	-0,563	0,000 (**)	0,220	0,204 (Ns)
	Cl^- (mg/L)	-0,662	0,000 (**)	-0,036	0,838 (Ns)
	Organic Matter (mg/L)	0,307	0,072 (Ns)	0,369	0,029 (*)
	Orto PO_4^- (mg/L)	0,056	0,750 (Ns)	0,299	0,081(Ns)
	NH_4^+ (mg/L)	-0,070	0,689 (Ns)	0,393	0,019 (*)
	NO_3^- (mg/L)	0,210	0,227 (Ns)	-0,099	0,571 (Ns)
	Na^+ (mg/L)	-0,605	0,000 (**)	0,008	0,964 (Ns)
	K^+ (mg/L)	0,006	0,974 (Ns)	-0,118	0,499 (Ns)
	Turbidity (NTU)	0,367	0,030 (*)	0,436	0,009 (**)
	pH	0,034	0,846 (Ns)	-0,372	0,028 (*)
	Temperature (°C)	-0,119	0,494 (Ns)	-0,099	0,571 (Ns)

Electrical Conductivity (µs/cm)	-0,505	0,002 (**)	-0,411	0,014 (*)
Dissolved O_2 (mg/L)	-0,254	0,141 (Ns)	-0,137	0,431 (Ns)
TDS (mg/L)	-0,923	0,000 (**)	-0,556	0,001 (**)

*: There is a relationship between the variables at 5% significance level.

**: There is a relationship between variables at 1% significance level.

Ns: There is no relationship between variables.

The analysis of the Söğütözü Creek watershed revealed no correlation between streamflow and pH levels. Similarly, in the Terme Creek watershed, researchers did not observe an inverse relationship between streamflow and pH measurements. As a matter of fact, Gökbulak et al. (2008) concluded that there was a negative relationship (P<0.001) between streamflow and pH as a result of thinning treatment in a study conducted in Istanbul Belgrad Forests. They stated that the change in streamflow after 11% timber harvesting in the watershed covered with beech forest directly affected pH. On the other hand, Kurunç et al. (2005) reported that there was no significant relationship between pH and streamflow in their observation study on water quality in Yeşilırmak River. Therefore, it is thought that the size of the watershed may affect the relationship between pH and streamflow. The disparity in size and configuration of the two watersheds directly influences the duration for surface water to exit the watershed. The duration required for winter snowfall to melt and exit the watershed is contingent upon the watershed's size, shape, form factor, and drainage network attributes. In the Söğütözü Creek watershed, the alteration in water temperature transpires within a significantly reduced timeframe. In addition, it is asserted that the rise in water temperature results in variations in the concentration of dissolved oxygen (Safonov and Kovalenko 1993). Consequently, the indirect effects of water temperature must also be considered. A significant correlation between streamflow and salt concentration was identified in the Söğütözü Creek Watershed and Terme Creek watershed. Kubo et al. (2006) indicated that salt concentration is directly correlated with streamflow and water velocity in the Mekong River in China, with salt concentration peaking when velocity and streamflow diminish. This robust correlation between streamflow and salt has been extensively examined in numerous modeling studies (Sierra et al., 2004; Liua et al., 2007). No correlation was identified between streamflow and dissolved oxygen levels in either watershed. Igbinosa and Okoh (2009) noted seasonal variations in specific physico-chemical parameters of water quality in their research conducted in South Africa. The study indicated that only the seasonal variation of dissolved oxygen was statistically significant. Consequently, the correlation between streamflow and dissolved oxygen in the study can only be elucidated through seasonal classifications. The distinct characteristics of the two watersheds result in semantic variations in the relationship between turbidity and flow. Rak et al. (2010) indicated that the correlation between streamflow and turbidity varies across the three watersheds examined in their study in Malaysia. Nevertheless, upon evaluating all watersheds, it was determined that the rise in streamflow corresponded with an increase in turbidity. The notable correlation between streamflow and phenolphthalein alkalinity in Söğütözü Creek Watershed is believed to stem from the region's geological composition of andesite bedrock. The presence of soluble solids from andesite bedrock, which are abundant in calcium, elevates the alkalinity of the water (Göksu, 2003). A comparable outcome was observed in a study by Kurunç et al. (2005) conducted in the Yeşilırmak watershed. The substantial correlation between streamflow and methylorange alkalinity in the Terme Creek watershed is attributed to the progressive decline in pH and the concomitant rise in methyl orange alkalinity during the assessment period. The water hardness in both watersheds results from the dissolved calcium and magnesium salts. The hardness of water is primarily influenced by the geological formations in or on which it is situated, resulting in considerable regional variations (Munsuz and Ünver, 1995). Upon examination of the geological structure of both watersheds, it is evident that their bedrocks are abundant in calcium and magnesium. This geological structure (andesite and high calcium oxide content of andesite) caused a strong relationship between streamflow and calcium hardness in the Söğütözü Creek watershed. A substantial correlation was identified between chloride concentration and streamflow in the Terme Creek watershed. Kurunç et al. (2005) identified an inverse correlation between streamflow and chloride in their research. Given the dimensions of the Terme Creek watershed and the proportion of residential and agricultural zones to the total watershed area (85%), it is presumed that the chloride concentration in the water is introduced artificially. The amalgamation of plant, domestic, and agricultural waste into stream water elevates chloride levels in the environment, thereby constraining the habitats of numerous invertebrate and aquatic organisms (Jones et al. 2002). In the Söğütözü Creek Watershed, it was found that a significant relationship between streamflow and organic matter can be observed during wet periods rather than dry periods. Zhang et al. (2009) supported this finding and emphasized that there is a stronger relationship between flow and organic matter during wet periods. In this direction, this relationship could not be observed in the Terme Creek watershed due to the decrease in streamflow with decreasing precipitation starting from June. A notable correlation was identified between streamflow and sodium concentration in the Terme Creek watershed ($r= -0.605$, $p<0.01$). Interlandi and Crockett (2003) and Serengil et al. (2007) indicated in their research that sodium and chlorine ions are transported en masse, with their concentrations in water rising predominantly during winter months. They proposed that the stream's streamflow yields more pronounced results regarding salt accumulation in winter. Chlorine measurements conducted in the same watershed exhibited a correlation with sodium. The anticipated gradual cooling and potential freezing of water temperatures in the Söğütözü Creek Watershed from November onward disrupted the correlation between sodium content and streamflow in this region. The Pearson Correlation Test revealed no significant relationship between streamflow and orthophosphate in either watershed. Nevertheless, orthophosphate concentrations in both watersheds attain maximum levels during the summer. Sigleo and Frick (2007) indicated in their research that orthophosphate levels are high in spring and summer relative to winter months. The primary cause of this relationship is the rise in orthophosphate concomitant with the increase in nitrogen levels during the summer months. The Pearson Correlation Test results indicate a significant relationship between streamflow and ammonium levels in Söğütözü Creek Watershed. The high streamflow period coincides with the onset of the vegetation season in the research area, and the stream bank's dense forest cover is believed to contribute to this relationship in the Söğütözü Creek Watershed. Meynendonckx et al. (2006) indicated that the onset of the vegetation period significantly accelerates ammonium accumulation, particularly due to decomposition at the stream edge. No substantial correlation was identified between streamflow and nitrate concentration in either watershed. Furthermore, some researchers have observed increased nitrate concentrations in stream waters during low flow conditions (Dinnel and Bratkovich, 1993; Yin et al., 1995; Manoochehri et al., 2010). This phenomenon is evident in the Terme Creek watershed; however, it is not observed in the Söğütözü Creek watershed.

Trends in Low Flow Indices

Trend analyses of river flows in Turkey have been conducted to date. Nonetheless, while trend analyses are conducted at a point scale, they fail to yield precise outcomes for regional scale interpretations (Kalaycı and Kahya, 1998; Topaloğlu, 1999; Önöz and Bayazıt, 2003; Kahya and Kalaycı, 2004; Topaloğlu, 2006). To address this issue, a regional Mann-Kendall Test was devised to assess the variable in a regional context (Yue and Wang, 2002). The regional Mann-Kendall test, applied due to the semi-arid climate of both watersheds, indicated a declining trend in annual average streamflows over the years. The Q95 flow process index is a prevalent metric utilized as an indicator of low flow conditions (Riggs, 1980; Brilly et al., 1997; Smakhtin, 2001; Tharme, 2003). According to Petts et al. (1997), the Q95 method is a critical tool for identifying the minimum flow required to protect stream ecosystems. The regional Mann-Kendall Test revealed a significant downward trend ($p<0.01$) in the Q95 flow process index from 1967 to 2010 in the semi-arid study area. Birhanu et al. (2007) indicated that seasonal variations and characteristics can lead to substantial alterations in trends within watersheds situated in the same region of Malaysia. Also, the Q90 flow process index has been utilized for various applications in low flow studies. Yulianti and Burn (1998) emphasized that the Q90 flow process index method is crucial for determining the minimum monthly flow required to sustain aquatic habitats. It has been utilized for modeling discharge time in minor streams (Ogunkaya, 1989) and for establishing the threshold value for critical flow levels (Rivera-Ramirez et al., 2002). The regional Mann-Kendall Test showed that there was no significant trend in the Q90 flow process index from 1967 to 2010. On the other hand, the Q75 flow process index, a hydrological method for calculating low flows globally, is less commonly utilized than Q95, Q90, and Q50, yet it is extensively employed in the USA (Smakhtin, 2001). The Regional Mann Kendall Test indicated that there was no significant trend in Q75 values in the study area from 1967 to 2010. Additionally, the Q50 index, employed globally to assess low flow for various applications, determines the minimum seasonal flow required in rivers utilized for hydropower (Metcalfe et al., 2003). Nonetheless, it is an index applicable in semi-humid and humid regions rather than in arid and semi-arid zones. The Regional Mann Kendall Test indicated no trend in the Q50 values in the study area from 1967 to 2010. Furthermore, the 7Q1 low flow index is recognized and utilized as the flow index for arid regions (Smakhtin, 2001). The analysis revealed that there was no trend in the 7Q1 low flow index within the study area from 1967 to 2010. The research by Cıgızoğlu et al. (2004) revealed that 7-day streamflows exhibit a declining trend in the Aegean, Eastern Black Sea, Mediterranean, and Eastern Anatolia Regions. A study utilizing the 7Q1 index revealed, through the Mann-Kendall Test, that some watersheds in China exhibited significant trends in 7Q1 flow values, while others displayed no discernible trend (Yang et al., 2009). They attributed the differing trends to the distinct characteristics of the watersheds, despite their location in the same region. The reduction of low runoff indices in semi-arid regions is attributable to several factors, including climatic influences, vegetation density, and anthropogenic activities (Cheng et. al., 2018). Climate change results in high temperatures, which enhance evapotranspiration in the region (Ruzzante and Gleeson, 2024), while diminished precipitation causes a reduction in runoff (Farahani & Khalili, 2013). Moreover, increasing deforestation and vegetation degradation in semi-arid areas intensify low flow conditions by reducing water retention in the basin (Vicente-Serrano et al., 2012; Trancoso et al., 2017). Low flow conditions have undergone trend analyses, as demonstrated in our study, to assess the impacts of climatic and anthropogenic activities (Farahani & Khalili, 2013; Coch & Mediero, 2016). Consistent with our research, other scholars have indicated that low flow conditions in the downstream basin have become more pronounced, with a comparable trend attributed to the construction of ponds and reservoirs in the upstream basin, as well as water extraction from the stream for agricultural purposes (Haghighi et al., 2020; Gebremicael et al., 2020; Uygur Erdogan and Ediş, 2024).

CONCLUSION

In this study we analyzed the flow variations, and water quality of two creeks situated in the semiarid Central Anatolian region. Water abstraction from rivers for agricultural purposes during the summer season has significantly degraded water quality. This finding underlines the need for a more intelligent and sustainable use of water resources at the regional level.The high turbidity and nitrate levels in the Terme Creek watershed indicate the necessity for regulating fertilizer application in agricultural practices. Long-term analyses of average streamflows indicate a significant reduction in water availability, necessitating the establishment of regional policies and plans for sustainable watershed-based water management. Despite varying trends in the region as indicated by low flow indices (Q95, Q90, Q75, Q50, 7Q1), the upward trend in the minimum streamflow essential for the aquatic ecosystem in the Söğütözü watershed necessitates the gradual restriction of water usage in this area. Future research should include prolonged observation durations, supplementary parameters like heavy metals and micropollutants, and a comprehensive analysis of seasonal influences to improve the generalizability of the results. Furthermore, modeling studies evaluating the impacts of agricultural and industrial activities can improve water management strategies.

COMPLIANCE WITH ETHICAL STANDARDS

a) Authors' Contributions

Each of the authors contributed 50%.

b) Conflict of Interest

The authors declare that there is no conflict of interest.

c) Statement of Human Rights

Work does not require a legal permit.

d) Statement of Human Rights

This study does not involve human participants.

e) Supporting Institution

Çankırı Karatekin University Scientific Research Projects Coordination

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