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RESEARCH ARTICLE

Evaluation of Water Quality in a Highly Impacted Urban Stream Using Water Quality Index (Ankara Stream, Türkiye)

Hazal Aydoğdu Kayadelen[1]*, Nilsun Demir[2]

[1]Graduate School of Social Sciences, Ankara University, Ankara, Türkiye https://orcid.org/0000-0002-5382-6119
[2]Department of Fisheries and Aquaculture Engineering, Faculty of Agriculture, Ankara University, Ankara, Türkiye https://orcid.org/0000-0002-3895-7655

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Abstract: Population growth along with other factors such as industrial, agricultural, and urban development, threaten freshwater resources in urban areas. Protecting urban water quality for ecological balance, water security, and energy production is crucial. The water quality index (WQI) provides an effective tool for assessing and managing water quality, and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) is one of the extensively used method. In this study, the pollution status of the Ankara Stream which flows through the densely populated Ankara was examined using physico-chemical parameters collected from five stations (S1-S5), and the water quality status was estimated via CCME-WQI. The results revealed varying water quality across different points on the stream. S2, located in a protected area, exhibited the best quality; in contrast, S4 and S5, located downstream of a wastewater treatment plant, exhibited the poorest quality. The consistency of these findings with the literature and the historical records of Ankara Stream emphasize that the CCME-WQI can be used for the management of water resources with high levels of pollution. This study contributes to sustainable water management practices and highlights the need for advanced treatment techniques to control pollution in urban freshwater resources.

Anahtar kelimeler:

CCME-WQI
Ankara Çayı
Kentsel su kalitesi
Kirlilik değerlendirmesi

Su Kalite İndeksi Kullanılarak Yüksek Derecede Etkilenen Kentsel Bir Akarsuda Su Kalitesinin Değerlendirilmesi (Ankara Çayı, Türkiye)

Öz: Nüfus artışı ile sanayi, tarım ve kentsel bölgelerdeki gelişim gibi çeşitli nedenler, kentsel tatlı su kaynaklarını tehdit etmektedir. Ekolojik denge, su güvenliği ve enerji üretimi için kentsel su kalitesinin korunması yüksek öneme sahiptir. Su kalitesi indeksi (WQI), su kalitesinin değerlendirilmesi ve yönetimi için etkili bir yöntemdir ve Kanada Çevre Bakanlığı Konseyi Su Kalite İndeksi (CCME-WQI), bu yöntemlerin en yaygın kullanılanlarından birisidir. Bu çalışmada, yoğun nüfuslu Ankara şehrinin içinden akan Ankara Çayı'nın kirlilik durumu, beş istasyondan (S1-S5) elde edilen fiziko-kimyasal parametreler kullanılarak incelenmiş ve su kalitesi CCME-WQI ile tahmin edilmiştir. Sonuçlar, çayın farklı noktalarında değişen su kalitesini ortaya koymuştur. Korunan alanda bulunan S2, en iyi kalite değerine sahipken, atık su arıtma tesisinin mansabında bulunan S4 ve S5, en kötü kaliteyi sergilemiştir. Bu bulgular, Ankara Çayı'na ait geçmiş veriler ve literatür ile tutarlılık göstererek, CCME-WQI'in yüksek kirliliğe sahip su kaynaklarının yönetimi için kullanılabileceğini ortaya koymaktadır. Bu çalışma, sürdürülebilir su yönetimi uygulamalarına katkıda bulunmakta ve kentsel tatlı su kaynaklarındaki kirliliği kontrol etmek için ileri arıtma tekniklerine duyulan ihtiyacı vurgulamaktadır.

Introduction

Urban freshwater resources, an essential part of urban ecosystems, are exposed to pollution due to increasing population pressure. Apart from basic sectors such as industry and agriculture, traffic and urban building are also sources of water pollution. Urban water bodies are deteriorated by diverse pollutants such as metals, organic compounds and nutrients through rainfall and waste waters from various sectors (Saravanan et al., 2021). Accumulation of large quantities of pollutants in the waters, which exceeds the water's carrying capacity, disrupts the natural ecosystem of water and threatens all aquatic life and human health (Satterthwaite, 2011). For this reason, it is crucial to study and reduce water pollution, especially at the urban level. Protecting water quality and safety, especially in densely

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*Corresponding author: aydogdu.hazal@gmail.com

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populated urban areas, requires strict planning and management in a broad framework (Hoekstra et al., 2018).

Good management of rivers plays a crucial role in supporting the natural infrastructure by providing ecological balance, as well as in issues related to drinking and irrigation water and energy production for large populations. However, simple and understandable data are needed due to the interdisciplinary nature of communication between stakeholders (Friberg, 2014). The usable water quality information, supported by scientific and standard methods, created using large-scale monitoring data and reflecting the actual situation can be reached using Water Quality Index (WQI) methods.

WQIs are optimized using specific statistical methods and provide a clear representation of a large amount of data. Therefore, they facilitate the use of data on water masses in the basins where monitoring studies are carried out and supply the knowledge for decision-makers to organize the management of that watershed (Liou et al., 2004). Additionally, they generally provide a rating for water quality, and the provided information can be used in managing water sources (Tyagi et al., 2013). CCME-WQI is a model used to demonstrate and document water quality in a more straightforward way (CCME, 2001). This model can provide a precise analysis of water quality parameters. CCME-WQI also tolerates missing data and provides many advantages in cases where some data cannot be produced due to setbacks in the field or laboratory. However, CCME-WQI usually does not give a detailed evaluation of water quality; instead, a broad overview of the ecological capability of water is obtained (Yan et al., 2016). CCME-WQI gives a single number for a location representing numerous variables assessed in different seasons. The index allows the user to select the parameters for more specific reasons, making it flexible. Besides the advantages, the information about individual variables and relationships between variables can be lost when reduced to a single number to determine the water class. Similarly, the index is unsuitable for biological parameters; all parameters have the same importance in the index, and CCME-WQI is ineffective in separating the importance of parameters (Terrado et al., 2010). Nevertheless, Canadian WQI is still one of the most frequently applied indices, as it is easy to use and gives inclusive and representative results.

CCME-WQI has also been used in European countries that apply Water Framework Directive (Zotou et al., 2020; Teodorof et al., 2021; Yotova et al., 2021). According to the comparative evaluation of CCME-WQI and Water Framework Directive (WFD) based quality estimation method for Greece, it is stated that CCME-WQI is a convenient tool for WFD implementation, especially because it allows the addition of toxic pollutants to the calculation procedure (Gikas et al., 2020).

Water quality estimation has been made for many years in Türkiye by applying water quality indices in lakes, streams, ground waters and wetlands. Among these works are the Universal WQI (UWQI), developed by Boyacıoğlu (2007) and first used in the Tahtalı Reservoir Basin, and the Lagoon WQI (LWQI), developed by Taner et al. (2011) and explicitly designed for the Lagoon ecosystem. In addition, international water quality indexes such as CCME, The National Sanitation Foundation Water Quality Index (NSF-WQI), Aquatic Toxicity Index, and Overall Index of Pollution were also used to determine the biological and chemical status of Kirmir Stream (Tunc Dede et al., 2013), Aksu and Acısu Creek (Tunc Dede and Sezer, 2017; Uslu et al., 2024), Karasu River (Alver and Baştürk, 2019), Melendiz River (Baştürk and Alver, 2019).

Türkiye’s environmental problems and priorities evaluation report from 2020 states that 35% of surface water is Class 4 poorest quality, while only 26% of surface water sources are Class 1 quality (Ministry of Environment and Urbanization Report, 2020). Also, it is reported that domestic and industrial wastewater, municipal solid wastes, fertilizers and pesticides cause the most pollution. Ankara, the capital of Türkiye, is one of the cities with freshwater-related problems as its primary concern. High urbanization and population increase lead to pressure and additional load on Ankara’s main water treatment center, (Tatlar Central Wastewater Treatment Plant, TWWTP) the intense stress on the wastewater treatment plant results in the poorest quality of water, Class 4. As a result, Ankara's urban greywater footprint exceeds the assimilation capacity for total nitrogen (TN), total phosphorus (TP) and ammonium, showing the need for urgent action for an increase in the scope and capacity of the plant (Kutlu, 2022).

The demand for freshwater is increasing in Ankara, primarily due to population growth and socio-economic development. In order to achieve a sustainable way of water usage, innovative tools and accurate estimations of current quality status should be used for water management systems. This study aims to examine the pollution status of Ankara Stream with various physico-chemical parameters and to estimate water quality with CCME-WQI using 26 water quality parameters.

Material and Methods

Study area and sampling

Ankara Stream is formed by the merging of Çubuk Stream and Hatip Stream in the Çubuk district. İncesu Stream which receives the waters of Mogan and Eymir Lakes, Ova Stream which passes through Mürted Plain, and Haymana Stream flow into Ankara Stream. Ankara Stream has a length of 140 km and 3153 km² of basin area (Figure 1). Ankara Stream merges with Sakarya River in Eskişehir. Sakarya River is the third biggest river in Türkiye, with a length of 720 km and a high flow rate with an annual value of 12 billion m³. It covers an area of 7% of Türkiye’s land before being discharged into the Black Sea (TUBITAK MAM, 2013). Sakarya Basin, with 80 of 855 Urban Sensitive Areas and 91 of 844 Nitrate Sensitive Areas, is one of the most delicate areas in Türkiye regarding water quality (GDWM, 2021). The water is polluted due to excessive industrialization and agricultural activities in large cities such as Eskişehir and Ankara (Akbulut et al., 2022).

The locations of the stations are given in Figure 1 and Table 1. The samples from these stations were examined for water quality parameters in the General Directorate of State Hydraulic Works (SHW) chemistry laboratories. Water samples were taken from various locations representing potentially different pollution levels: S1 and S2 were far from residential areas and S3, S4 and S5 were from more polluted water bodies, close to residential and industrial regions and a water treatment plant (TWWTP).

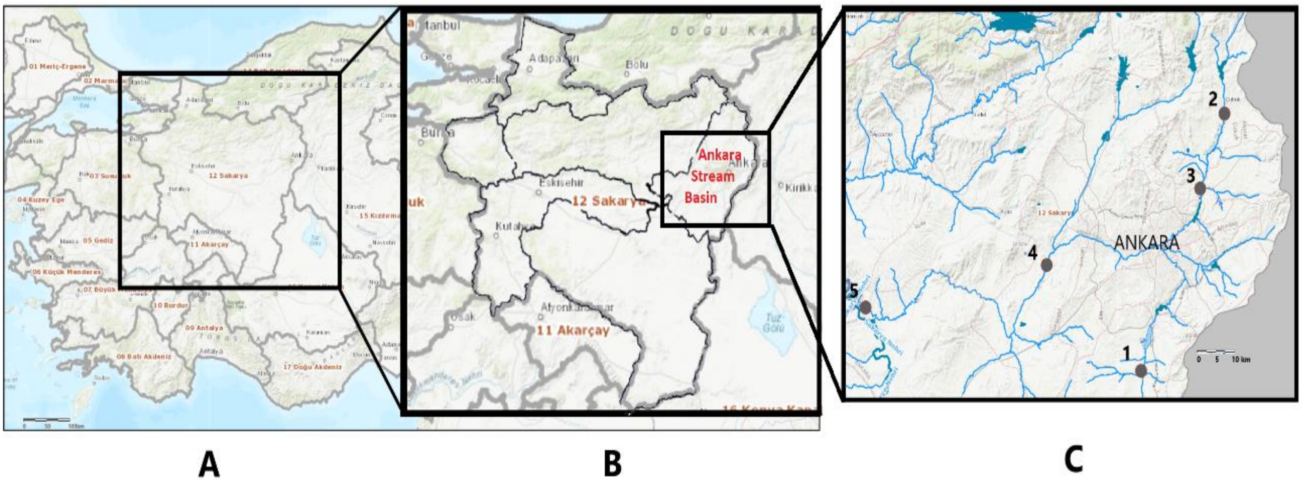

Figure 1. The location of the Sakarya River Basin (A), the Ankara Stream Basin and other subbasins of the Sakarya River Basin (B) and the locations of the stations in the Ankara Stream Basin-gray dots (C)

Table 1. The location and the coordinates of the sampling stations in Ankara Stream

Station number	Station 1	Station 2	Station 3	Station 4	Station 5
Code	S1	S2	S3	S4	S5
Latitude (N)	39° 41' 28.886"	40° 10' 55.688"	40° 3' 34.355"	39° 56' 18.000"	39° 48' 53.317"
Longitude (E)	32° 46' 35.559"	33° 1' 6.214"	32° 57' 16.321"	32° 29' 21.700"	31° 56' 8.581"

Sampling was performed in five periods: February, May, August, November 2019, and February 2020. Data covering one year was used for the index calculations. However, for Station 2, sampling could not be performed in August 2019 and November 2019 due to the drying of the stream bed. In the sampling process, the requirements of the TS ISO 5667-6 were complied with (ISO, 2014).

CCME-WQI calculation

The index value, which results from three factors called Scope, Frequency and Amplitude, provides a general assessment of water quality with a value on a scale of 0-100. Water quality status was determined according to a series of calculations according to CCME (2001):

The percentage of parameters exceeding the limit values relative to the total parameters:

$$\text{Scope} = \text{F1} = \frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} * 100 \ \text{(Eq. 1)}$$

The percentage of failed tests to the number of tests performed in all times:

$$\text{Frequency} = \text{F2} = \frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} * 100 \ \text{(Eq. 2)}$$

And the amount of deviation of failed tests exceeding the limit value was calculated in three steps:

a. Excursion is a value that shows the deviation of a parameter from the limit value and was calculated with one of the following equations, which was appropriate,

i. When the failed test value was over the limit value:

$$\text{excursion} = \frac{Failed\ test\ value}{Objective} - 1 \ \text{(Eq. 3)}$$

ii. When the failed test value was below the limit value:

$$\text{excursion} = \frac{Objective}{Failed\ test\ value} - 1 \ \text{(Eq. 4)}$$

iii. When test value was zero:

$$\text{excursion} = Failed\ test\ value \ \text{(Eq. 5)}$$

b. The collective amount of the deviation values of each failed test was calculated as:

$$\text{nse} = \frac{\sum_{i=1}^{n} excursion_i}{Total\ number\ of\ tests} \ \text{(Eq. 6)}$$

c. F3 was calculated by scaling the normalized sum of the excursions from objectives (nse).

$$\text{Amplitude} = \text{F3} = \frac{nse}{0.01nse + 0.01} \quad \text{(Eq. 7)}$$

With these factors CCME-WQI score was calculated as follows:

$$\mathbf{CCME - WQI\ score} = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right] \quad \text{(Eq. 8)}$$

Table 2. The parameters that are used for the CCME-WQI calculations with units, limit values and standards

Parameter	Unit	Limit Value	Limit Source	Analysis Method	Standard
pH		6<=pH<=9	EQS	pH Electrometric	TS EN ISO 10523
EC	µS/cm	400	EQS	Conductivity Electrode	TS 9748 EN 27888
DO	mg/L O_2	>8	EQS	Electrochemical Probe	TS EN ISO 5814
BOD	mg/L O_2	4	EQS	Electrochemical Probe	STMD 5210
COD	mg/L O_2	25	EQS	Open Reflux – Titrimetric	STMD 5220B
Total Nitrogen	mg/L N	3.5	EQS	UV Spectrophotometric	STMD 4500N
Ammonia Nitrogen	mg/L NH_4^+-N	0.2	EQS	Ion Chromatography	TS EN ISO 14911
Nitrite Nitrogen	mg/L NO_2	0.1	TS266	Ion Chromatography	TS EN ISO 10304-1
Nitrate Nitrogen	mg/L NO_3^--N	3	EQS	Ion Chromatography	TS EN ISO 10304-1
Total Kjeldahl Nitrogen	mg/L N	0.5	EQS	Distillation and Titration	STMD 4500NH_3
Total Phosphorus	mg/L P	0.08	EQS	Colorimetric	TS 7889
Sulphate	mg/L SO_4^{-2}	250	EQS	Ion Chromatography	TS EN ISO 10304-1
Fl	µg/L F^-	1000	EQS	Ion Chromatography	TS EN ISO 10304-1
Cl	mg/L Cl^-	250	TS266	Ion Chromatography	TS EN ISO 10304-1
Na	µg/L	200	TS266	Ion Chromatography	TS EN ISO 14911
K	mg/L	20	WHO2011	Ion Chromatography	TS EN ISO 14911
Se	µg/L	10	EQS	ICP-MS	EPA 200.8
Cd	µg/L	5	TS266	ICP-MS	EPA 200.8
Ni	µg/L	20	EQS	ICP-MS	EPA 200.8
Al	µg/L	300	EQS	ICP-MS	EPA 200.8
An	µg/L	5	TS266	ICP-MS	EPA 200.8
As	µg/L	20	EQS	ICP-MS	EPA 200.8
Cu	µg/L	20	EQS	ICP-MS	EPA 200.8
Ba	µg/L	1000	EQS	ICP-MS	EPA 200.8
Zn	µg/L	3000	WHO2011	ICP-MS	EPA 200.8
Co	µg/L	10	EQS	ICP-MS	EPA 200.8

EQS (RSWQM, 2012), TS266: Drinking water standard limits (TS 266, 2005), WHO 2011 (WHO, 2011)

The value obtained from the calculation was used to make a classification according to the CCME guideline (CCME, 2017; Khan et al., 2004). The five-level scale, as defined by the CCME, were color-coded to make them more coherent throughout the article. The following color codes were assigned to CCME WQI values: blue for 95-100 (excellent), green for 80-94 (good), yellow for 65-79 (fair), orange for 45-64 (marginal) and red for 0-44 (poor).

For the calculation of Ankara Stream CCME-WQI, SHW provided the data. The parameters used in index calculation were measured according to the standard methods in Table 2. Since the calculation employs the deviations of actual values from ecological quality standards, Ecological Quality Standards (EQS) were used as the primary source. Regulation on Surface Water Quality Management (RSWQM, 2012) and Turkish standard, water intended for human consumption (TS 266, 2005) were also used. WHO Guidelines for drinking-water quality (WHO, 2011) were used for the parameters for which the national guideline did not specify a standard value.

Results and Discussion

Chemical properties

The results of the 26 parameters tested in the water samples taken from five stations and in five periods covering one year were evaluated. The descriptive statistics for analysed physico-chemical parameters are listed in Table 3.

The pH values ranged between 7.5-8.75 throughout the sampling period for all the sampling stations, meeting the standard values given in the EQS. However, the concentrations of pollutants such as nitrogen compounds and heavy metals increased from stations S1 and S2 to S3 and eventually to S4 and S5. S1 and S2 were located upstream, S3 is in the populated area, and S4 and S5 were downstream of the Ankara Stream.

The DO concentrations were high at stations S1, S2 and S3, and were sufficient to support natural freshwater habitats. The annual mean values of DO from S1 to S5 were 9.51, 10.62, 8.37, 6.55 and 4.65 (mg O_2/L), respectively. It has been observed at all stations that DO concentrations decreased in the summer months when temperatures were high (Balls et al., 1996). Differences in upstream and downstream O_2 levels may be due to lower organic pollution in rural areas.

COD and BOD showed a similar trend. The mean BOD was 2.8 mg/L for S1, and it showed an increasing trend towards the downstream, reaching up to 128.8 mg/L in S5. The mean COD value for S5 was 164.5 mg/L, which indicated the increasing trend downstream due to organic pollution.

Nitrate (NO_3) levels were the most affected by fertilizer use. The nitrate concentrations were found as 6.48, 2.59, 3.09, 2.53 and 1.77 mg/L, from S1 to S5, respectively. Higher nitrate levels indicated agriculture induced pollution in S1 and S2.

TN and TP levels for all sampling stations were higher than those reported for the environmental quality standards. Except for S1, TP levels failed to reach the EQS value. According to the Sakarya River Basin Action Plan prepared by TUBITAK MAM, Ankara Stream Basin has severe pollution load due to the high population in the region. Ankara Stream Basin had 13% non-point and 87% point TP load (TUBITAK MAM, 2013). Elevated levels of TN are generally associated with sewage water coming from households. The highest values reached up to 34.54 mg/L downstream of the highly populated districts of Ankara.

Downstream of the treatment plant (S4 and S5), TP content showed a dramatic increase. This increase may be due to the industrial discharges and the treated municipal discharges, which are rich in detergents. These stations are located downstream of the densely populated area of the river. Results indicated high TP and TN levels at S4 and S5 with a higher risk for eutrophication, revealing that TWWTP is unable to reduce these pollutants. Therefore, there is an urgent need for increasing the wastewater treatment capacity and providing treatment in accordance with environmental standards.

In addition to organic pollution, inorganic pollutant concentrations at S4 and S5 are well above the standard levels. It has been determined that heavy metals Cd, Ni, Al, As and Cu increased significantly downstream of densely populated areas and industrial zones. Heavy metals can be poisonous to humans and other organisms, even in low amounts (Qu et al., 2018). The maximum value of As (60.7 µg/L) was found in S1, and the values in S3, S4 and S5 were also high. S1 is located at the inlet of Lake Mogan and high As concentration resulting from agricultural and industrial activities was identified as having the biggest contribution to metal pollution in the creeks which fed the lake (Pulatsü & Latifi, 2023a). Hence, it is essential to consider heavy metals while determining the water quality status. For example, excessive levels of Al (6054 µg/L) and Cd (669 µg/L) indicated the severity of impact. The elevated levels of heavy metals are mainly caused by discharges from industrial activities. Implementing and enforcing stringent environmental regulations for industries and promoting the adoption of cleaner technologies and sustainable practices reduces industrial pollution in industrial areas. It is also crucial to prevent industrial wastewater from being released into the Ankara Stream without adequate treatment before reaching the discharge points. Urban run off is also considered as a major cause for heavy metal pollution (Ghadiri et al., 2023).

CCME-WQI

The results of water quality index calculations are shown in Table 4 and Figure 2. According to the table, the water quality status of S1-S5 ranged between marginal, fair and poor.

Table 3. Descriptive statistics for the analysed physico-chemical parameters used in the CCME-WQI calculations (minimum, maximum, and mean values ±standard deviations)

			STATION 1			**STATION 2**			**STATION 3**			**STATION 4**			**STATION 5**		
#	Parameter	Unit	Min	Max	Mean ± SD	Min	Max	Mean. ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
1	pH		8.04	8.75	8.32±0.26	7.87	8.1	7.97±0.1	7.53	8	7.88±0.17	7.35	7.96	7.72±0.18	7.35	7.82	7.54±0.06
2	EC	µS/cm	235	2070	707±686	89	771	348±301	119	1395	908±430	119	1522	1000±587	91	1637	854±638
3	DO	mg/L	6.87	10.88	9.51±1.40	9.44	12.29	10.62±1.22	4.49	10.8	8.37±2.12	2.57	9.1	6.55±1.93	2.36	7.25	4.65±1.16
4	BOD	mg/L	1	7	2.8±2.1	1	6	3.7±2.1	2	13	7±4.2	5	130	42.8±35.28	18	280	128.8±26.9
5	COD	mg/L	8.12	14.09	10.56±2.28	10.21	10.6	10.41±0.2	11.36	23.65	14.94±5.05	11.36	240.39	110.56±92.81	28.98	331.37	164.50±44.27
6	Total N	mg/L	3.44	11.65	7.09±3.42	2.2	3.86	3.26±0.75	4.23	9.35	5.89±1.87	3.43	40.85	19.96±13.24	3.43	40.85	21.09±6.96
7	NH_4 N	mg/L	0.094	0.598	0.346±0.252	*	*	*	0.091	3.693	1.304±1.194	0.129	8.006	4.068±0.444	8.737	12.987	10.265±3.11
8	NO_2 N	mg/L	0.074	0.517	0.296±0.222	0.078	0.472	0.275±0.197	0.051	2.656	0.805±0.479	0.051	0.76	0.373±0.335	0.042	0.76	0.237±0.016
9	NO_3 N	mg/L	2.959	10.548	6.482±3.228	1.314	3.413	2.594±0.917	1.457	4.091	3.092±0.906	0.969	4.091	2.53±0.602	0.969	2.414	1.768±0.188
10	Total Kjeldahl N	mg/L	0.17	0.61	0.47±0.16	0.3	0.73	0.48±0.18	0.19	4.64	1.99±1.75	0.19	39.86	18.36±13.85	0.26	39.86	19.39±7.05
11	Total P	mg/L	0.014	0.115	0.054±0.034	0.166	0.287	0.222±0.05	0.172	0.802	0.355±0.232	0.172	1.254	0.593±0.563	0.193	1.703	1.24±0.254
12	SO_4	mg/L	435.42	1159.94	803.65±304.81	71.86	106.76	85.25±15.36	69.86	110.51	90.55±13.3	79.14	223.62	130.82±50.35	79.14	236.04	155.15±16.4
13	Fl	mg/L	0.48	2.16	1.03±0.58	0.15	0.36	0.23±0.09	0.17	0.38	0.28±0.09	0.17	0.58	0.33±0.09	0.36	0.58	0.44±0.06
14	Cl	mg/L	221.58	554.5	387.78±136.66	47.09	352.62	152.47±141.59	69.14	182.44	121.37±43.5	78.74	157.88	121.82±41.25	78.74	185.87	127.69±37.16
15	Na	mg/L	311.58	980.4	648.58±269.88	33.66	195.8	92.71±73.15	62.72	153.26	102.94±34.28	74.28	188.63	125.05±46.36	74.28	188.63	136.92±22.34
16	K	mg/L	2.65	9.44	6.34±2.40	5.51	11.04	8.65±2.32	8.21	15.69	12.48±3.46	10.72	15.69	13.26±8.39	9.74	32.02	16.12±7.34
17	Se	µg/L	3.95	4.1	4.03±0.08	*	*	*	**	**	**	**	**	**	2.53	12.87	7.7±0.53
18	Cd	µg/L	**	**	**	**	**	**	*	*	*	54.49	76.73	65.61±21.41	4.39	669.07	192.97±7.68
19	Ni	µg/L	3.53	54.09	18.61±11.89	3.19	3.9	3.55±0.36	3.19	16.55	7.78±5.30	3.19	22.25	12.6±6.22	19.41	35.04	26.59±23.99
20	Al	µg/L	115.9	538.83	346.58±171.83	105.3	147.1	130.7±18.2	213.1	481.96	328.27±96.99	308.9	5357	3412±2330.86	649	6054	3287±1648
21	An	µg/L	**	**	**	*	*	*	*	*	*	0.44	0.73	0.59±0.16	0.36	0.71	0.5±0.14
22	As	µg/L	8.53	60.74	26.94±23.93	4.69	6.12	5.6±0.65	3.28	46.28	14.35±10.64	3.81	54.71	18.94±12.93	11.65	59.48	39.73±12.68
23	Cu	µg/L	1.62	107.98	34.37±24.75	13.23	23.92	17.48±4.63	8.44	23.47	14.59±6.26	8.44	67.32	29.59±16.59	30.87	67.32	48.49±25.19
24	Ba	µg/L	72.48	160.27	115.17±33.88	117.2	170.8	143.1±21.92	72.05	116.7	95.79±18.62	72.05	121.58	97.18±25.72	97.13	176.28	128.55±34.54
25	Zn	µg/L	18.47	143.27	80.68±50.95	30.92	103.46	61.05±30.86	36.7	68.14	49.81±11.49	45.35	1360	455.39±338.42	323.7	2644.91	949.61±53.78
26	Co	µg/L	0.83	0.89	0.86±0.03	0.4	0.55	0.48±0.08	0.39	0.87	0.62±0.17	0.55	2.44	1.12±0.75	1.36	4.22	2.56±0.93

Minimum, maximum and standard deviation could not be calculated at points with * insufficient data ** results below the LOQ

Table 4. Factors and overall water quality values for the stations

Station	F1 Scope	F2 Frequency	F3 Amplitude	CCME-WQI	Status
S1	61.53846	31.66667	31.45197	56.10875	Marginal
S2	34.61538	17.80822	11.36856	76.58563	Fair
S3	42.30769	25.83333	29.94161	66.5635	Fair
S4	57.69231	42.5	86.1426	35.30601	Poor
S5	50	45.83333	87.44828	36.10265	Poor

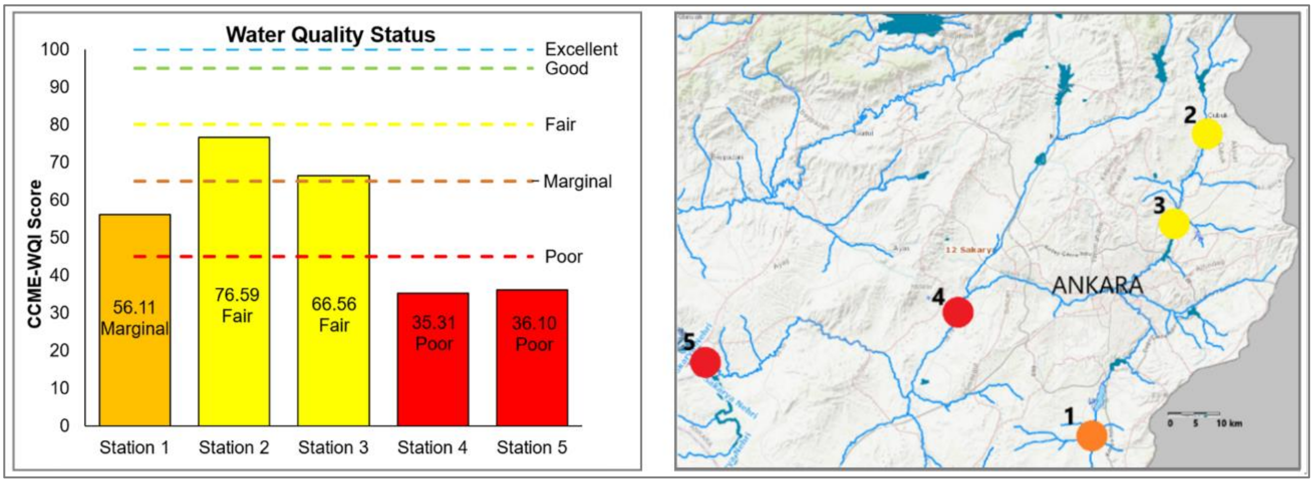

Figure 2. The color-coded water quality status for the sampling stations in accordance with the CCME-WQI scores

CCME-WQI values indicated "Marginal" quality in S1 which is located at the inlet of Lake Mogan. High values of EC, Total N, SO_4, Cl, Na, Al, As and Cu concentrations showed severe pollution. It was reported that polluted creeks flowing into Lake Mogan pose a risk to human health (Pulatsü & Latifi, 2023b). S2, located within a protected area, had a CCME-WQI score of 76.59, indicating a "Fair" quality status and representing the best quality among the sampling stations. Various measures were taken to safeguard the water and natural ecosystem in the region, which was designated as a protected area due to its importance as a drinking and utility water source. This region is a sensitive area where surface freshwater sources are vital for drinking water supply. Stringent precautions are taken to minimize anthropogenic impacts in sensitive areas, as high nitrate concentrations may occur if no preventive measures are in place (Bütünoğlu, 2018). S3 had a "Fair" water quality. This station is located at Çubuk Stream, close to a settlement where agricultural activities are also carried out. High TP and TN values can also be associated with these human-induced activities. S4 and S5 had "Poor" water quality. S4 is located downstream of TWWTP, Türkiye's largest wastewater treatment plant, which treats domestic and industrial wastewater from Ankara city center using activated sludge process and discharges it to Ankara Stream. It has a daily treatment capacity of 765,000 cubic meters (ASKİ, 2020) but currently can not effectively remove N and P (TUBITAK MAM, 2013). There is already an upgrade plan to increase the capacity of the plant to about 1,377,000 cubic meters per day to serve a population of approximately six million by 2025. S5 is located at Ankara Stream before it merges with the Sakarya River. The concentrations of EC, DO, BOD, COD, TP, TN, Cd, Ni, Al, As and Cu in S4 and S5 were higher than EQS limits. Consequently, organic and inorganic pollution continue to remain high at S4 and S5.

Pollution levels observed at points along Ankara Stream are in accordance with the historical data from earlier reports (Kazancı and Girgin, 1998; Atıcı and Ahıska, 2005). A recent study on Ankara Stream in 2018 estimates the quality of water by using NSF-WQI (Durmuş, 2021). According to this study, the water quality status in the upstream was determined to be Medium and Good in different seasons. However, it was stated that the water quality declined downstream and considered "poor" (Durmuş, 2021). While our findings agree with those of Durmuş (2021) in terms of consistency, it is important to note that flexibility in the type and number of variables chosen and allowance of the use of various quality standards that can be selected according to the research purpose to test water quality makes CCME-WQI a more reliable method (Chidiac et al., 2023). In addition, including heavy metals has proven to be advantageous while dealing with polluted waters. Interpreting pollution parameters with a single index value provides a useful tool in terms of water management.

Conclusion

In this study, CCME-WQI scores were determined for five stations on Ankara Stream to determine the water quality. The results showed that the water quality status of Ankara Stream was successfully estimated with WQI method and revealed a decrease in water quality from upstream to downstream, particularly in densely populated and industrialized areas.

The index shows that the quality of the water bodies highly varied depending on the location. S1 is located at the inlet of Lake Mogan and showed marginal quality status. Within a protected area, S2 has a higher score and maintains better water quality due to reduced human impact. S3 has also fair water quality but worse than S2 and this station is near to residential areas. The poor quality status of S4 and S5 stations, signals the need for urgent upgrades in the treatment plant, especially for N and P. The findings also align with previous research, emphasizing the ongoing pollution challenges Ankara Stream faces.

In conclusion, population growth and rapid urbanization increase the water demand, and therefore, a multidisciplinary approach and sustainable management practices have become essential. Protecting and improving urban water quality, especially in densely populated regions such as Ankara, becomes necessary for ecological balance and human welfare. Recent research trends in Türkiye focus on water quality indices, and this study shows that CCME-WQI can quickly and reliably estimate water quality status for regulatory purposes, thanks to the flexibility it provides in parameter selection and allowing the use of quality standards that can be selected according to the research purpose.

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Conflict of Interest

The authors have no competing interests to declare that are relevant to the content of this article. No funding was received for conducting this study. The authors declare they have no financial interests.

Author Contributions

The conception and design of the study were performed by both authors. The manuscript was written by the corresponding author and the second author read and commented on the previous versions. All authors read and approved the final manuscript.

Ethics Approval

No ethics committee approval is required for this study.

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