REPUBLIC OF TURKEY
ANKARA UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
DEPARTMENT OF WATER POLICY AND SECURITY

THE USE OF WATER QUALITY INDEX FOR THE ESTIMATION OF WATER QUALITY IN ANKARA STREAM

MASTER'S THESIS

Hazal AYDOĞDU KAYADELEN

Thesis Supervisor

Prof. Dr. Nilsun DEMİR

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I hereby declare that all information in my master thesis titled "The Use of Water Quality Index for The Estimation of Water Quality in Ankara Stream (Ankara, 2022)" which has been prepared under Prof. Dr. Nilsun DEMİR's supervision has been gathered and submitted in accordance with academic rules and ethical conduct principles and the data obtained from other sources have been duly indicated both in the text and references. I also declare that I have acted according to scientific research and ethical rules during the study process and if otherwise come forth, I will accept all legal consequences.

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ABBREVIATIONS

EQS	Environmental Quality Standards
WFD	Water Framework Directive
DSI	General Directorate of State Hydraulic Works
WQI	Water Quality Index
CCME	Canadian Council of Ministers of Environment
SYGM	General Directorate of Water Management
RSWQM	Regulation on Surface Water Quality Management
EU	European Union
EPA	American Environment Agency
LOQ	Limit of Quantitation
TP	Total Phosphorus
TN	Total Nitrogen
WHO	World Health Organization
µS/cm	Microsiemens/ Centimeter
DO	Dissolved Oxygen
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
SO_4^{-2}	Sulphate
NO_3	Nitrate

NO_3-N	Nitrate Nitrogen
NO_2-N	Nitrite Nitrogen
NH_4 -N	Ammonia Nitrogen
PO4	Phosphate

1. INTRODUCTION

Water is the main component for life on earth and it must be carefully managed because it is not a limitless source. Freshwater sources are already scarce and access to clean and sufficient water becomes more challenging every day. Today, freshwater resources are not only play vital role but also have high economic value. Humanity uses water in various sectors like agriculture, industry, energy production, transportation. These sectors use water intensively and these activities affect the amount and quality of water available (Gleick, 1993). The increasing population further accelerates the rate of this effect (Liyanage and Yamada, 2017). It has become essential to develop new coping skills and strategies for future generations.

The impact of human pressure on water quality and ecology has not been an issue for a long time. Environmental policies in Europe began in the 70s and improved with Environmental Action Plans prepared under the European Commission's Environmental Action Program. In the first Environmental Action Plan published for 1973-1976, the foundations of the sustainability concept have been founded and the direction of the environmental policies has been revealed (Giacoumis and Voulvoulis, 2018). The reflection of this ecology focused movement on the management of water resources was established with the European Union Water Framework Directive (EU WFD) in 2000, which was valid for the member states.

With the new approach, the management style of water resources was also revised and new strategies were developed with the concept of sustainability at the focus. In order to develop administrative action, it is necessary to find out the ecological status of the water. After the implementation of some monitoring programs, the obtained data are effectively handled and used in water status estimations (dos Santos Simoes et al., 2008).

Water Quality Index (WQI) offers a way to minimize the mess of the large monitoring data and give information about river quality for a specific watershed. This way the WQIs supply the knowledge for decision makers to organize the management about that watershed.

1.1. Aim of the Thesis

According to Turkey's environmental problems and priorities evaluation report of 2020, 67% of surface water is grade 4 quality where only half of the remaining surface water sources comprises grade 1 quality. It is also reported that the majority of the pollution is caused by domestic and industrial wastewaters, municipal solid wastes and the use of fertilizers and pesticides. Ankara, the capital of Turkey, is one of the cities that have freshwater related problems as primary concern. High urbanization and population increase caused pressure and additional load on Tatlar Central Wastewater Treatment Plant (Anonymous, 2020).

The demand for freshwater is increasing in Ankara, primarily as a result of population growth and socio-economic development. In order to achieve a sustainable way of water usage, smart tools should be applied to water management systems. Management starts with knowing the current state and monitoring activities. The data obtained from monitoring can be interpreted through WQI models. The importance of monitoring the quality of rivers will be put forward by taking the case of Ankara Stream, which is an important example of anthropogenic pollution, passing through the city of Ankara.

The aim of the thesis is to estimate the water quality status by using the Canadian Ministry of Environment Council-Water Quality Index (CCME-WQI) in Ankara Stream. The data covering one year between February 2019 and February 2020 is used for the index calculations, because of the COVID-19 pandemic period, monitoring studies have been disrupted after this date.

2. LITERATURE REVIEW

2.1. Ecological Approaches in Water Management

The EU WFD is seen as a groundbreaking document for the Member States. The Directive foresees that, with new legal approaches, water bodies should be managed across the river basins; taking into account their natural geographic and hydrological conditions, not national or political boundaries (European Commission, 2000). In addition, it has directed the coordination of the member states to ensure that all European waters are in 'good ecological and chemical status' (Kallis and Butler, 2001).

Ecological good status determined for surface waters supports life in water ecosystems by setting minimum standard values for rivers and lakes. With the WFD Annex V, standards for biological, chemical and hydrological factors necessary for the life of biological elements in water have been established (European Commission, 2000). However, in this case, there cannot be a single standard that can be used for different regions. Thus, the necessity to develop new standards locally to support aquatic ecosystem emerges. Although dealing with many parameters locally results in complications, it is inevitable and mandatory in order to conserve biological diversity in a holistic manner.

Similarly, chemical good status is explained as the compliance with defined quality standards for chemical substances in all European countries. Besides giving special importance to nitrates, pesticides and fertilizers, directive offers a mechanism that enables prioritization of substances that can be updated according to the results of monitoring activities.

For the evaluation of groundwater, biological status is not examined while an additional quantitative analysis is required according to WFD. Because the amount is a major issue for these resources. The directive presents an innovative policy by using integrated approach on management of both surface water and groundwater.

Along with the target of reaching good status, “no deterioration” provision is also introduced by the regulation to avoid water quality deterioration. To prevent worsening of all waters has become another goal for all waters.

Reaching these standards, in which human impact is tried to be minimized, did not happen at the expected time period. The year 2015 was set as the first goal, and it was postponed to 2021 in order to achieve coordination of EU member states. However, since the elimination of the high anthropogenic effect takes many years and not creating additional deterioration in industrialized regions requires supplementary technologies, year of 2027 is set as the new target for good condition in all waters.

2.2. WFD Implementation in Turkey

Before adapting to WFD, water management in Turkey was performed through the administrative boundaries by authorities of institutions that are determined by laws. Each institution has carried out activities related to water resources within the framework of their authorities. When management duty is shared by several institutions, it resulted in a disorganized structure (Karadağ, 2008). The most comprehensive work in this regard has been undertaken by the large central and provincial organization and the General Directorate of State Hydraulic Works (DSI).

Water quality and quantity management were separated from each other in water resources management infrastructure before basin-based water management. The quantity management of water was under the responsibility of DSI under the Ministry of Agriculture and Forestry, while the quality management was conducted by General Directorate of Environmental Management under the Ministry of Environment, Urbanization and Climate Change. In addition, water quality measurements were carried out by laboratories in DSI regional directorates in designated surface waters. Conflict of powers and responsibilities caused problems in practice. For this reason, scientists and experts working in this field have mentioned the necessity of transition to the river basin management system, which is seen as a more effective water management method and which has recently been used in Europe (Meriç, 2004; Karadağ, 2008; Dalkılıç and Harmancıoğlu, 2008)

Turkey has been included in this process with the EU environment acquis compliance task as an EU candidate country. In this process, first of all, it has been proposed that both the public and the private sector should carry out the investments required for the transposition and implementation of EU legislation and then to ensure full alignment (Dalkılıç and Harmancıoğlu, 2008). However, later the implementation of the WFD has begun and the activities have been accelerated after General Directorate of Water Management (SYGM) was established (Official Gazette, 2011). Several EU-funded projects have been carried out in this context, studies were started for monitoring and management in river basins and various regulations entered into force in Turkey (Anonymous, 2014; Official Gazette, 2014, Official Gazette, 2016). The primary aim of the mentioned studies and published regulations is to find out the current situation of all freshwater sources in terms of biological, chemical and hydromorphological elements. In addition, the procedures and principles to be applied are also determined by this way in order to ensure coordination among the monitoring institutions and organizations. Turkey has been divided into 25 river basins, and studies have been initiated to manage these basins according to integrated river basin management.

According to the directive, monitoring activities are one of the most challenging parts of the management as it requires a spreading network for field work and qualified laboratories. This task is assigned to DSI because the organization and infrastructure is more convenient. The main purpose of monitoring applications is to estimate the water quality and to develop policies according to the state of water.

2.3. Water Quality Monitoring

Monitoring is an essential component of integrated river basin management. To find out the water quality and the measures to be taken in future stages, monitoring works are carried out in the basins. A significant innovation in monitoring in the implementation of the WFD is the monitoring of biological quality together with the chemical quality of water.

Chemical monitoring is collection of chemical data from any body of water for various purposes and assessments. Pollutants can be discharged into freshwater resources as a product or by-product of many activities such as agriculture, industry, domestic waste, etc. (Tueros et al., 2009). Pollution of surface waters with these chemicals leads to degradation of aquatic ecosystems and reduction of biodiversity. In addition, pollutants entering the food chain cause harmful effects as a result of increasing their amount at every step from the lowest point of the chain to the living things at the highest point. Therefore, it is necessary and essential to monitor chemicals through a program.

Biological monitoring is the assessment of a water body's capacity to support an ecosystem by periodically monitoring aquatic organisms (e.g., macroinvertebrates, fish, phytobenthos) and supplementing it with chemical and physical data. Aquatic organisms are used as meaningful indicators for ecology of the water because they deal with chemical, physical and biological effects in their habitats throughout their entire aquatic life cycle, which can be multiple years in some cases. Thus, in addition to the current water status obtained by chemical monitoring, information for overall condition is obtained with biological monitoring (Bartram and Ballance, 1996).

Finally, another monitoring activity implemented according to the directive is hydromorphological monitoring. Hydromorphological features affect the characteristics, quality and diversity of habitats, which are the living areas of organisms. Hydromorphological quality elements are found to be fundamental for ecology-based river basin management as these elements are evaluated by referencing to the natural conditions (Meier et al., 2013).

After all these monitoring studies, a huge data pool is formed on numerous quality parameters. When the quality parameters are evaluated separately, they usually do not give an overall information about the quality of the water. In order to overcome this problem, numerical models have been created in which the parameters can be integrated. A wide variety of models have been studied for different purposes and different type of water bodies (Olowe, 2018; Tsakiris and Alexakis 2012). One of the most common models for determining the quality of surface waters is water quality index (WQI). In this study, water quality estimation will be made using the monitoring data of a river using a WQI.

2.4. Water Quality Indices

Water resources should be managed with appropriate strategies according to their intended use. Models that take into account physical, chemical and biological factors are needed to ensure that the water is in the desired state for intended purpose on the basis of a river basin.

Although the idea and necessity of categorizing waters according to their pollution dates back to the mid-1800s, it took more than a hundred years to rate water with water quality indices (Lumb et al., 2011). Since the first WQI was proposed by Horton (1965), various indices have been used to objectively and reproducibly indicate a water status of data on chemical and biological variables. These methods are utilized to reveal the combined effect of the measured parameters. They have begun to diversify for different regions and different purposes as they are used frequently (Landwehr, 1979).

Indices allows a large amount of data to become easily understandable by a variety of statistical methods and gives the whole water quality information (Liou et al., 2004). They provide a rating to quality of water and the provided information can be used in managing water sources (Tyagi et al., 2013).

As Uddin et al. (2021) explained, WQI typically covers four phases:

1. Firstly, water quality parameters of interest should be selected. For various purposes, different criteria need to be used. For example, the use of the turbidity

parameter in the quality calculation for drinking water and agricultural irrigation water may vary.

2. Water quality data should be transformed to a dimensionless sub-index and prepared for use in the subsequent stages.

3. A weighting factor should be determined for each water quality parameter. Again, for different models and purposes, the value of each criterion and its impact on the final quality estimation changes.

4. A single numerical value expressing the water quality status is reached by using different weight factors and sub-indexes with a function determined by statistical methods.

Indices can be based on physico-chemical, biological as well as hydromorphological parameters. For freshwater bodies, there are some essential parameters that are measured for almost every sample taken from each station. Physical parameters such as temperature, color, turbidity and solids are generally the first ones to be measured at site or in the laboratory. EC, pH, dissolved oxygen, chemical oxygen demand, biological oxygen demand, nitrate are chemical parameters and fecal and total Coliform parameters give information about biology of water. These are also the most commonly used parameters in quality indexes (Lumb et al., 2011). These parameters are the mostly studied elements of freshwaters, as they are highly influential on aquatic life and show the state of water body.

Some parameters to be considered in the constitution of the index to determine the quality are examined below.

pH: Most aquatic organisms live in a very narrow pH range. This range corresponds to neutral pH and its surroundings. Therefore, if the pH is at critical values, this parameter can be used to evaluate the vitality of the water (Mount, 1973).

EC: EC indicates the ability of electricity to pass through water and is directly related to the amount of ions in the water (Marandi et al., 2013).

Dissolved Oxygen (DO): This parameter refers to gaseous oxygen and takes a critical task in the respiration. DO is one of the most critical components that show the health of the aquatic ecosystem (Saari et al., 2018).

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD): BOD and COD are indicators of organic pollution. Organic inputs cause the usage of oxygen in the water. This value is also important for the health of the ecosystem, because there is a risk of complete depletion of dissolved oxygen and the life dependent on DO may be affected (Sharma and Gupta, 2012).

Nitrate and Phosphorus: Nitrate and phosphorus are the main nutrient sources of phytoplankton and macrophytes. Excessive production of these biological elements may cause eutrophication (Hornung, 1999). High nitrate and organic nitrogen concentrations in surface waters are an indicator of organic pollution via human waste or manures (Pulatsü et al., 2014).

In addition to the basic parameters given above, quality parameters that are specific to region and/or purpose are also used in WQI design (Banda and Kumarasamy, 2020). There are WQIs designed and developed by various institutions and organizations around the world. The most used indices were supported by the National Sanitation Foundation of USA and Brown et al. (1970), the National Sanitation Foundation Water Quality Index (NSF-WQI) and by the Canadian Ministry of Environment Council Water Quality Index (CCME-WQI) (Katyal, 2011). Other commonly used indices can be listed as Oregon Water Quality Index (OWQI) and recently developed Malaysian Index (Uddin et al., 2021).

2.5. Water Quality Estimation in Turkey

In Turkey, the monitoring activities are conducted extensively according to WFD regulations. Particularly chemical and biological monitoring results in a large number of data and this data can be translated into meaningful information via WQIs. The state of water is given by processing the data through WQIs. CCME and NSF are most commonly used indices in Turkey along with indices about biological quality.

In 2007, Boyacıoğlu set out to generate a new index and developed a method called Universal Water Quality Index (UWQI), which uses pH, DO, BOD, arsenic, fluoride, cadmium, nitrate, phosphorus, mercury, selenium, cyanide and total coliform indicators, with the studies carried out in the Tahtalı Basin (Boyacıoğlu, 2007). For our country, the usage of water quality index is relatively new area. Some of the studies conducted in Turkey are given in Table 1.

Table 1. WQI studies reported in Turkey are given with the scope of the study and results

Reference	**Scope of the Study**	**Results**
Boyacıoğlu (2007)	**Tahtalı Basin** UWQI	It provides a simple representation for the general quality of water by using high number of physical, biological and chemical variables data.
Taner et al. (2011)	**Küçükçekmece Lagoon** Lagoon WQI (L-WQI)	With this study, an index for lagoon systems was developed. With L-WQI, changing number of variables can be tested and used as a simple method especially for deteriorated lagoons.
Dede et al. (2013)	**Kirmir Stream** CCME-WQI OWQI Aquatic Toxicity Index (ATI) Overall Index of Pollution (OIP) UWQI	Canadian and Oregon WQIs are found to be more representative of the area due to higher resolution they offer. ATI, OIP and UWQI underrepresented some parameters that are important for human health and ecology.
Dede and Sezer (2017)	**Aksu Creek** CCME-WQI	CCME-WQI was chosen because it can represent the water body without any limitation on the parameter number and it was stated that when compared with the limits specified in the standards, successful result was obtained with this index.
Koç (2018)	**Bodrum Peninsula** Weight Arithmetic Index WQI	This WQI method is found to be useful for evaluation and management of water quality as it gave results similar to real status of water.

Alver and Baştürk (2019)	**Karasu River** CCME-WQI OWQI NSF-WQI	They stated that OWQI and NSF-WQI enable the water resource to be evaluated seasonally. In addition, the CCME-WQI model is advantageous as it gives results on the basis of pollutants, determines which parameter affects the water quality at what level and offers the measures to be taken according to the parameter.
Baştürk and Alver (2019)	**Melendiz River** NSF-WQI Dinius WQI (Dinius, 1987)	These indices were selected as they can evaluate some water quality parameters monitored in the monitoring study. Both indices were found to be realistic.
Durmuş (2021)	**Ankara Stream** NSF-WQI	When the data obtained as a result of the NSF-WQI model application are compared with the water quality standards in the national legislation for each parameter, it is seen that the results are compatible and realistic. This shows that the NSF-WQI model has been successfully applied for Ankara Stream.

2.6. CCME-WQI

CCME-WQI is a model that is used to demonstrate and document water quality in a simpler way (CCME, 2001). This model can provide clear analysis of water quality parameters. However, CCME-WQI usually does not give a detailed evaluation of water quality, rather a broad overview of ecological capability of water is obtained.

The first step was the development of British Columbia WQI (BCWQI) which was developed by the British Columbia Ministry for Environment, Lands and Parks in Canada. BCWQI was later improved by CCME and the latest version has been tested in different water sources in many provinces of Canada and has been used throughout the country as it has been successful in these trials (CCME, 2001).

The index value, which is basically the result of three factors called Scope, Frequency and Amplitude (Figure 1), provides a general assessment of water quality with a value on the scale of 0-100.

Scope (F1): First factor shows the degree of failure against the limit values during the research period.

Frequency (F2): Second factor is a numerical representation of each test that fails against the limit values.

Amplitude (F3): Third factor gives a measure of how far the failed tests are from the limit values.

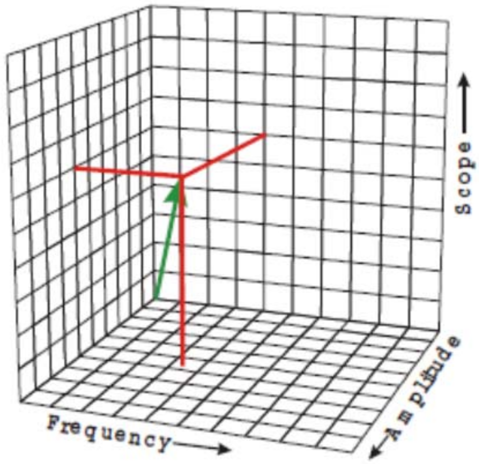

Figure 1. Theoretical model for CCME-WQI (CCME, 2001)

CCME-WQI gives a single number for a location representing many variables that are tested in different seasons. This single value can easily be compared with other locations and available to be used for large-scale research such as river basin management. For more specific reasons, index allows the user to select the parameters to be used and that makes it flexible. For example, the parameters to be selected for drinking water supply and the data to be used in determining the quality of surface waters differ and CCME-WQI adapts to various purposes.

The index simplifies complex statistical methods and makes it easy to apply for big data. Thus, it becomes easier to make a large number of data obtained from large areas easier to understand. CCME-WQI also shows tolerance to missing data and it provides many advantages in cases where some data cannot be produced due to setbacks in the field or laboratory (Yan et al., 2016).

The resulting single value is unitless because the index supplies a way to eliminate units of various measurements by proportioning the data with standard limit values. Through a table of water quality rating, a quality status is determined as a result of index calculation. The result becomes clear for a range of users, from managers to general public (Tyagi et at., 2013; Abbasi and Abbasi, 2012).

CCME-WQI has been also used in European countries that apply EU WFD (Zotou et al., 2020; Teodorof et al., 2021; Yotova et al., 2021) and United Nations Environmental Program (UNEP) also recommended this index as a proxy for drinking water sources in 2007 (UNEP GEMS, 2007). According to the comparative evaluation of CCME-WQI and 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 pollutant parameters to calculation procedure (Gikas et al., 2020).

CCME-WQI is compared with NSF WQI for adoptability to WFD and Groundwater Directive 2006/118/EC. The study found that the of CCME-WQI is highly compatible as it determines the deterioration and pollution levels (Alexakis, 2020; European Commission, 2006)

Besides the advantages listed above, the method has some drawbacks. For example, when reducing to a single number to determine the water class, information about individual variables and relationships between variables can be lost. Therefore, when using the CCME-WQI, depending on the purpose of the research variables that are important can also be considered separately (Terrado et al., 2010). Similarly, the index is not suitable for biological parameters, they can be evaluated with other specific indices such as Diatom Index or Index of Biological Integrity (IBI).

All parameters have the same weight in the index which can be counted as another disadvantage. Although some quality parameters have more influence on the quality of the water, CCME-WQI is not effective in separating the importance of these parameters (Terrado et al., 2010). However, Canadian WQI is still one of the most frequently applied indices, as it is easy to use and gives inclusive and representative results.

2.7. Water Quality of Ankara Stream Basin

Sakarya Basin, where Ankara Stream is located, is the basin where both Urban Sensitive Area (19 areas) and Nitrate Sensitive Areas (21 areas) are the most concentrated (Anonymous, 2017). The water is very polluted due to excessive industrialization and agricultural activities in large cities such as Eskişehir and Ankara (Akbulut et al., 2022). Studies investigating biological and chemical parameters have been conducted to determine the water quality in this highly polluted region.

In a study evaluating the ecological quality by using Oligochaeta species as biological indicators, it was stated that there are tolerant organisms adapted to environments with high organic pollution and low dissolved oxygen content (Kazancı and Girgin, 1998). This study is an indication that the pollution in Ankara Stream has been high for a long time. In another study, it was determined that algae with tolerance to pollution were intense. When chemical parameters introduced into evaluation, they found that Ankara Stream has the highest pollution class (Atıcı and Ahıska, 2005).

A study was conducted on Ankara and Çubuk Stream with data collected in 2018 from 10 stations to estimate the quality of water by using NSF-WQI (Durmuş, 2021). NSF-WQI offers five quality categories (Excellent, Good, Medium, Bad and Poor). According to this study, the water quality in the station located in the upstream region of Çubuk Stream was determined as Medium and Good in different seasons. However, it was stated that the water quality decreased as the downstream descended and the results were determined as Bad (Durmuş, 2021).

3. MATERIAL AND METHOD

3.1. Study Area

Sakarya River is the third longest river in Turkey with a length of 720 km. It is born near Eskişehir Çifteler, passing through many provinces and pouring into the Black Sea. The basin catchment area is 7 % of Turkey's land. The main tributaries of Sakarya River are streams of Seydi, Ankara, Porsuk, Mudurnu, Koca, Kirmir and Darıçay. Sakarya River Basin has a high flow ratio with an annual value of 12 billion m^3 (Figure 2). River passes through the provinces of Ankara, Afyon, Bolu, Bilecik, Bursa, Eskişehir, Kütahya, Konya and Sakarya (TÜBİTAK MAM, 2013).

Sakarya River originates from the springs in the Sakaryabaşı region, located in Eskişehir. The river empties into the Black Sea from the coast of Karasu District of Sakarya. Various climates are effective in the basin, which has an average elevation of 925 meters, due to its large area and location (Anonymous, 2018).

Ankara Stream Basin, our research area, is formed as a result of merging of Çubuk Stream and Hatip Stream originating in Çubuk district. Later, İncesu Stream, which empties the waters of Mogan and Eymir Lakes, Ova Stream, which passes through the Mürted Plain, and the water coming from Haymana mix into Ankara Stream. Ankara Stream merges with Sakarya River in Eskişehir. As a part of Sakarya River basin, Ankara Stream has a length of 140 km and 3.153 km² of basin area.

3.1. Sampling Stations

The locations of the stations are given in Table 2. The samples that are taken from these stations are examined for water quality parameters in DSI chemistry laboratories. SYGM determines which parameters will be studied during a season according to monitoring type of the surface water as such; surveillance, operational, investigative and protected area.

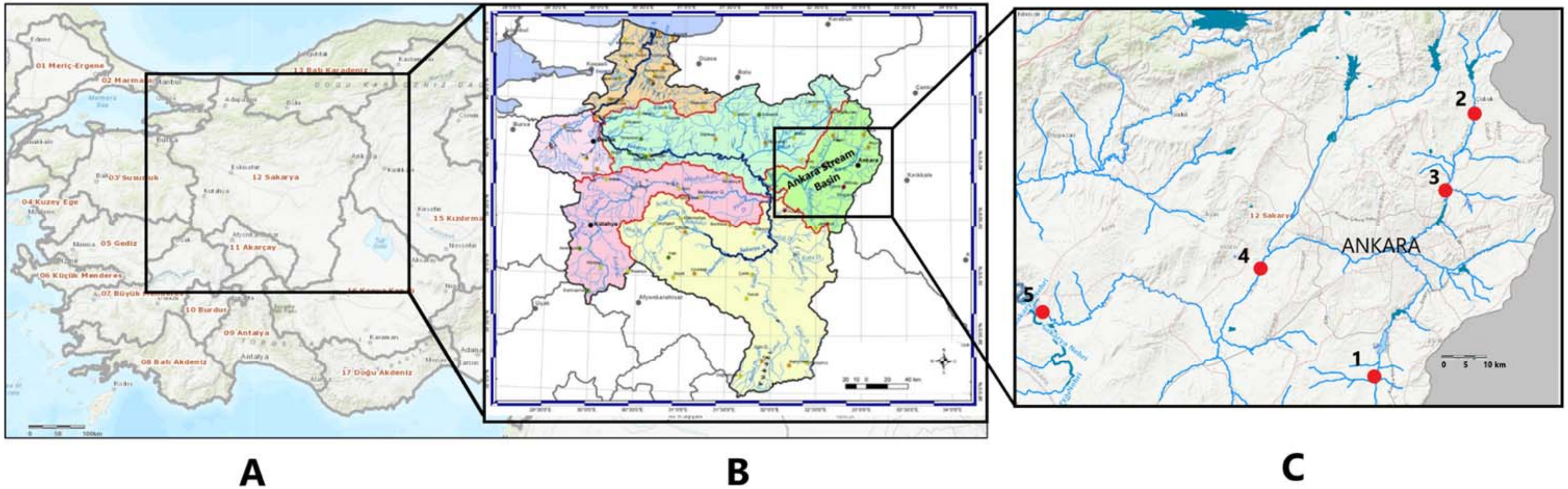

Figure 2. The location of Sakarya River Basin on Turkey map (A), Ankara Stream Basin and other sub-basins of Sakarya River Basin (B) and the locations of the stations on the water resources network (C)

Table 2. The location and coordinates of the sampling stations in Ankara Stream (DSI)

Station number	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**
Code	SAGİN 003	SAKAİN012	SAGİN029	SAGİN026	SAGİN023
Typology Code	TR120111631106	TR120111711113	TR120111721114	TR120111761121	TR120111781124
Water Body	Mogan Lake input	Çubuk Stream	Çubuk Stream	Ankara Stream	Ankara Stream
Monitoring Type	Surveillance	Protected Area	Surveillance	Surveillance	Surveillance
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"

The working area from Sakarya River Basin and the locations of the sampling stations on the water resources network is given in Figure 2. A detailed information about the stations is given below:

Station 1 (SAGİN003): This station is located on the water body that feeds Mogan Lake. Mogan Lake is a large shallow lake with an area of 6.35 km^2 in Gölbaşı district.

Station 2 (SAKAİN012): The station from which water samples are taken is a Protected Area on Çubuk Stream.

Station 3 (SAGİN029): This station is located on Çubuk Stream, close to the residential area in Altındağ.

Station 4 (SAGİN026): The station is located after Tatlar Wastewater Treatment Plant, which is affiliated to the local government of Ankara province, treats the wastewater coming from both domestic usage and 4 organized industrial zones of Ankara city center and discharges it to Ankara Stream.

Station 5 (SAGİN023): Last station is located on Ankara Stream before it merges with Sakarya River. This point is also located before the entrance of the Polatlı Gürsöğüt Dam.

Photographs showing the surroundings of the stations are also given in Figure 3. Samples are taken from areas where the water flow is natural and far from heavily modified channels. In the sampling process, the requirements of the TS ISO 5667-6 were complied with (ISO, 2008).

In the calculation of Ankara Stream CCME-WQI, data will be obtained from the National Water Database, which is covering a year period, which was created as a result of monitoring studies. Sampling was performed five times; February, May, August, November 2019 and February 2020. However, for Station 2, sampling could not be done in August 2019 and November 2019 due to the drying of the stream bed.

The parameters that are used in index calculation are measured according to standard methods given in Table 3. Table also gives the national standard limits for those parameters, which is necessary for CCME-WQI. For some parameters, international limits determined by the World Health Organization (WHO) were also used when there was no specified national standard limit.

Station 1

Station 2

Station 3

Station 4

Station 5

Figure 3. Images from and around the points where water samples were taken

Table 3. 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
Ar	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 (Official Gazette, 2012)
TS266: Drinking water standard limits (TS, 2005)
WHO 2011 (WHO, 2011)

3.2. CCME-WQI Calculation

For the estimation of CCME-WQI, three factors are calculated firstly (CCME, 2001):

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

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

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

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

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

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

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

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

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

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

iii. When test value is zero:

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

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

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

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

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

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

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

The constant in the last equation, 1.732, is a scaling factor that is used to fix the index outcome between 0 and 100.

Water quality status is determined according to the table below (Table 4) by taking the result of Equation 8, CCME-WQI score.

Table 4. The status of water according CCME-WQI values (Khan et al., 2004)

Status	CCME WQI Value	Color Code
Excellent	95- 100	
Good	80-94	
Fair	65-79	
Marginal	45-64	
Poor	0-44	

Explanation of the status of water according to Table 4 is given below:

Excellent: The waters in this state are in their natural state or very close to their natural state. In order to achieve this level, all parameters must be within the limits all the time.

Good: The waters in this state contain only a small amount of pollution factor. Conditions deviate slightly from natural levels and thus the water quality is preserved.

Fair: Although conditions are generally maintained in these waters, sometimes conditions are threatened or deteriorated away from desired levels.

Marginal: Conditions in these waters are often away from natural or desired levels and are therefore threatened or deteriorated.

Poor: Water quality in these waters is almost always in danger of contamination and conditions are far from natural or desired levels (CCME, 2017).

4. RESULTS AND DISCUSSION

For the determination of the quality of water in Ankara Stream Basin, WQI method is used. The data from five sampling stations, which were collected and produced by DSI laboratories, were used in calculation of CCME-WQI.

The data used for the calculation of CCME-WQI is given in Table 5. Ecological quality standard limits are important for this calculation where the limits are used from the Regulation on Surface Water Quality Management (RSWQM), Regulation on Quality and Purification of Drinking Water Supply Water and WHO (Anonymous, 2012; WHO, 2011). As shown in the table failed tests are written in red and other tests within the limit values are given in green. The test results with higher difference from the limit value effects the resulting status more.

It is clearly seen that, Station 4 and Station 5, that are located after Ankara Stream passes through the city center, have failed many of the parameters for all seasons.

Table 5. The laboratory test results for each station and each testing season taken from DSİ. (The failed tests are shown in red and the test results within limits are shown in green)

#	Parameter	Date	Feb. 2019	May 2019	Aug. 2019	Nov. 2019	Feb. 2020	Feb. 2019	May 2019	Feb. 2020	Feb. 2019	May 2019	Aug. 2019	Nov. 2019	Feb. 2020	Feb. 2019	May 2019	Aug. 2019	Nov. 2019	Feb. 2020	Feb. 2019	May 2019	Aug. 2019	Nov. 2019	Feb. 2020
		Unit	Station 1					Station 2			Station 3					Station 4					Station 5				
1	pH		8,4	8,04	8,04	8,37	8,75	8,1	7,87	7,95	8	7,93	7,53	7,96	7,96	7,5	7,35	7,82	7,66	7,38	7,5	7,68	7,59	7,6	7,53
2	EC	µS/cm	2070	334	458	440	235	771	89,4	184	943	920	1395	1164	119	1340	858	1522	167	90,6	1637	1330	1333	136	165
3	DO	mg/L	10,88	10,22	6,87	10,2	9,38	12,29	9,44	10,12	10,8	9,35	4,49	9,1	8,11	5,73	2,57	7,25	5,76	2,36	5,3	4,39	2,48	5,76	3,8
4	BOD	mg/L	1	2	7	2	2	1	6	4	2	4	11	5	13	48	130	18	280	170	46	70	80	120	110
5	COD	mg/L	<5	8,12	14,09	9,09	10,92	<5	10,6	10,21	<5	12,46	23,65	11,36	12,29	62,3		28,98	331,37	240,39	57,27	103	108,39	188,35	147,8
6	Total N	mg/L	5,45	3,44	11,65	10,72	4,17	3,73	2,2	3,86	4,71	9,35	6,31	4,23	4,84	9,85	40,85	3,43	17,95	27,74	15,49	18,74	18,21	34,54	17,02
7	NH_4 N	mg/L	<0,047	<0,047	0,094	0,598	<0,047	<0,047	<0,047	0,444	0,091	<0,047	3,693	<0,047	0,129	8,006	<0,047	<0,47	9,07	8,737	12,987	13,617	7,109	16,29	14,58
8	NO_2 N	mg/L	<0,018	<0,018	0,517	<0,018	0,074	<0,018	0,472	0,078	0,796	2,656	0,215	0,308	0,051	<0,018	<0,018	0,76	0,056	0,042	0,091	<0,047	0,051	0,054	0,057
9	NO_3 N	mg/L	5,265	2,959	10,548	10,093	3,543	3,413	1,314	3,055	2,979	3,2	1,457	3,734	4,091	1,441	0,969	2,414	<1,131	<1,130	1,92	1,449	1,455	1,449	1,448
10	Total Kjeldahl N	mg/L	0,17	0,46	0,58	0,61	0,55	0,3	0,41	0,73	0,93	3,5	4,64	0,19	0,7	8,39	39,86	0,26	16,76	26,57	13,48	17,19	16,7	33,04	15,51
11	Total P	mg/L	0,014	0,049	0,115	0,059	0,032	0,166	0,287	0,213	0,263	0,349	0,189	0,802	0,172	0,542	1,254	0,193	1,406	1,703	1,643	2,303	1,607	1,954	1,97
12	SO_4	mg/L	435,42	797,61	1159,94	1130,29	495	71,86	77,14	106,76	88,05	69,86	96,97	87,35	110,51	153,46	79,14	223,62	139,45	97,52	236,04	197,32	208,28	194,95	190,49
13	Fl	mg/L	0,76	0,83	2,16	0,94	0,48	0,36	0,19	0,15	0,36	0,3	0,38	0,17	0,19	0,34	0,36	0,58	0,44	0,37	0,47	0,43	0,46	0,34	0,32
14	Cl	mg/L	221,58	379,6	554,5	529,21	254,02	47,09	57,7	352,62	69,14	74,24	182,44	135,55	145,48	157,88	78,74	91,43	185,87	103,37	179,04	110,37	108,78	118,97	195,84
15	Na	mg/L	311,58	644,28	918,3	980,4	388,33	33,66	48,68	195,8	62,72	67,36	153,26	123,86	107,51	130,99	74,28	188,63	179,34	87,64	154,71	114,49	110,5	122,64	165,72
16	K	mg/L	2,65	6,21	9,44	8,34	5,08	9,4	5,51	11,04	8,21	8,32	14,75	15,69	15,45	13,03	10,72	11,41	32,02	9,74	16,73	0,31	18,48	20,03	18,61
17	Se	µg/L	4,1	<1,70		3,95	<1,70	1,17		<1,70	<0,60	<0,40		<0,90	<1,70	<0,60	<0,40		12,87	<1,70	2,53	<1,70		2,93	1,67
18	Cd	µg/L	<0,50	<1,0		<1,0	<1,20	<0,50		<1,20	<0,50	0,35		<1,0	<1,20	76,73	54,49		669,07	4,39	43,91	<1,0		37,55	56,07
19	Ni	µg/L	3,53	54,09		8,08	8,72	3,9		3,19	16,55	7,37		3,99	3,19	22,25	20,95		19,41	35,04	30,95	86,96		27,66	38,12
20	Al	µg/L	115,9	538,83		482,4	249,2	147,1	139,69	105,3	213,1	481,96		309,1	308,9	1586	5357		649	6054	1088,21	920,6		5036,12	2454
21	An	µg/L	<0,60	<0,60		<2,50	<2,60	<0,60		2,6	<0,60	0,5		<2,50	<2,60	0,73	0,44		0,36	<2,60	0,71	<2,60		0,43	<2,50
22	Ar	µg/L	8,53	<0,2		60,74	11,55	5,99	4,69	6,12	3,28	46,28		4,03	3,81	13,19	54,71		59,48	11,65	33,07	<0,2		44,98	14,19
23	Cu	µg/L	10,18	107,98		17,71	1,62	15,28	23,92	13,23	17,47	23,47		8,97	8,44	33,62	67,32		30,87	63,16	32,59	98,19		44,32	69,33
24	Ba	µg/L	94,81	160,27		133,1	72,48	117,2	141,13	170,8	116,7	111,02		83,39	72,05	111,7	121,58		176,28	119,2	97,13	184,09		105,07	114,7
25	Zn	µg/L	18,47	143,27		80,3	<2,20	30,92	103,46	48,77	36,7	68,14		49,04	45,35	1360	367,17		2644,91	323,7	462,66	339,19		374,42	460,2
26	Co	µg/L	0,89	<0,20		0,83	<0,20	0,55		0,4	0,39	0,87		0,55	0,65	0,82	2,44		1,36	4,224	2,21	4,04		2,15	4,05

4.1.Chemical Properties

4.1.1. Electrical Conductivity (EC)

Conductivity is the concentration of dissolved salts in water. Naturally, the geological structure and rainfalls significantly affect the electrical conductivity value of the aquatic environment (Cüce et al., 2020).

EQS value for EC is given as 400 µS/cm for I. Class water according to surface water regulation. There are stations exceeding this value because the natural course of water and the seasonal changes effects the ion balance due to the biochemical activities. However, for TS 266 (2005) standards, the EC value in drinking water should not exceed the limit of 2500 µS/cm for human health.

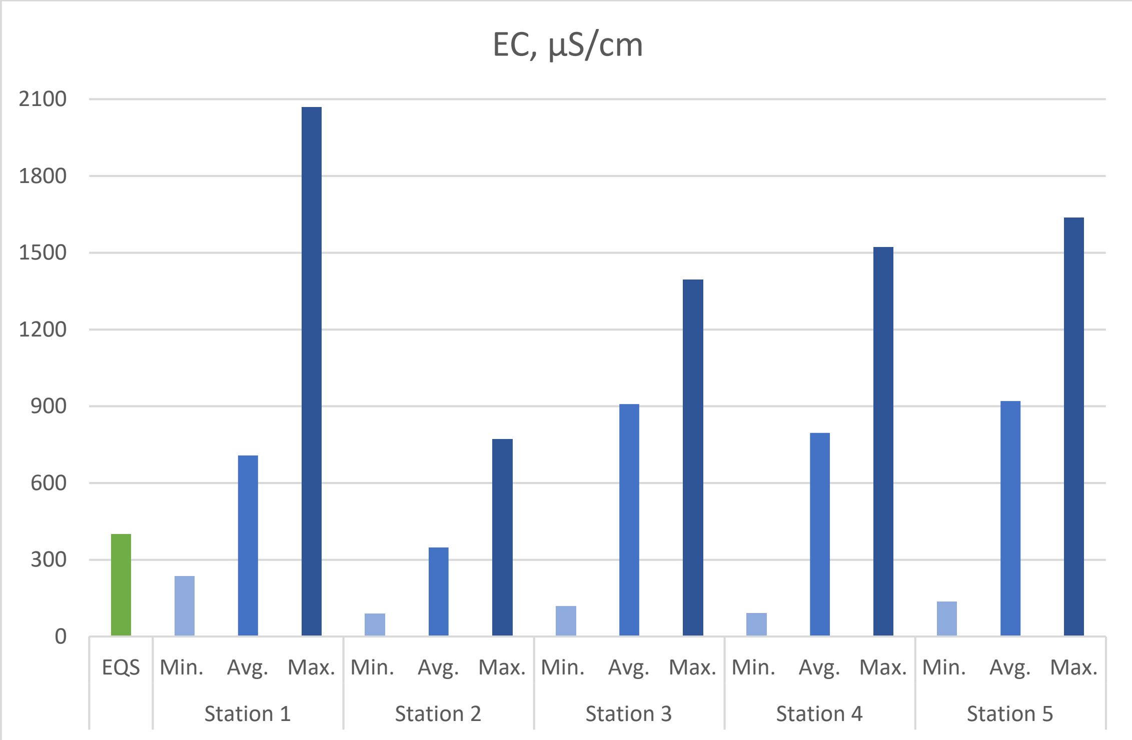

Figure 4. EQS value with respect to minimum, maximum and average EC values of sampling stations

4.1.2. Dissolved Oxygen, BOD, COD

DO ratio in the aquatic environment varies depending on the oxygen ratio in the air and the usage of aquatic organisms. In addition, factors such as water temperature, salinity, turbidity and pressure affect the dissolved oxygen ratio in water (Best et al, 2007).

The dissolved oxygen values at the stations 1, 2 and 3 the lowest DO values as 6.87, 9.44 and 4.49 mg O_2/L respectively were measured in summer season in August 2019 as it is also known that seasonal temperatures and water temperature are effective on dissolved oxygen (Balls et al., 1996). And similarly at lower temperatures in winter seasons in

February 2019 the highest DO values were obtained as expected. Station 4 and 5 gave low DO values which is expected due to the general water pollution in these water bodies.

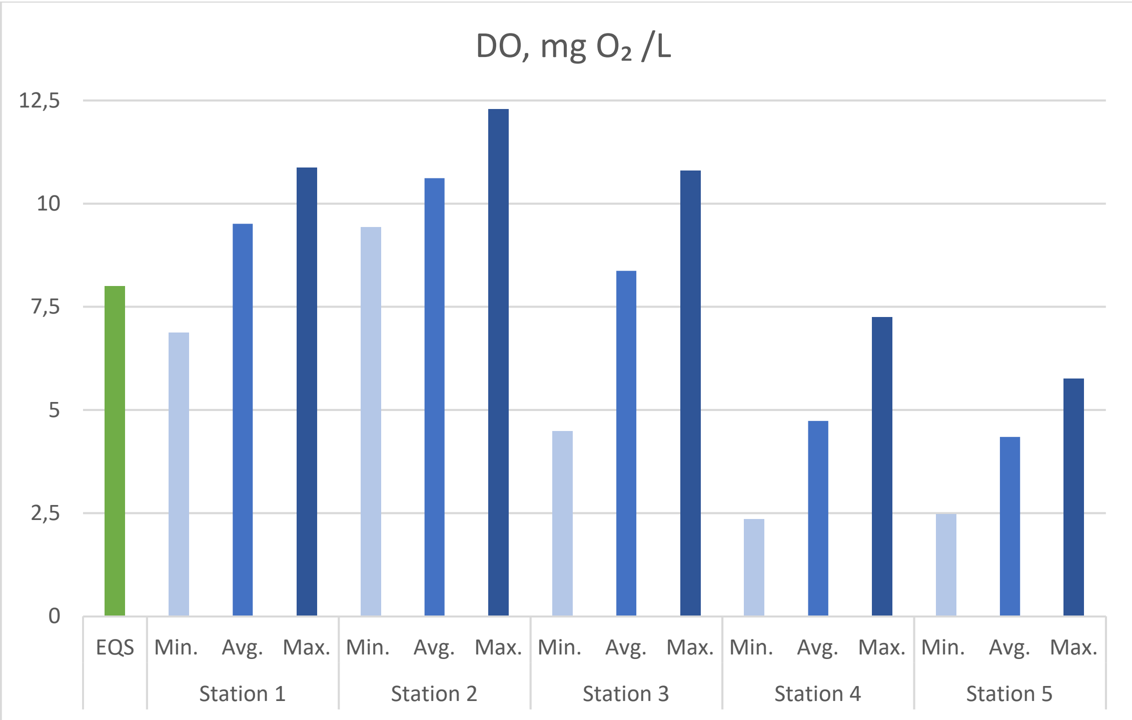

Figure 5. EQS value with respect to minimum, maximum and average DO values of sampling stations

BOD refers to the oxygen needed during the break down of organic matter. Pollution increases the amount of organic matter to be decomposed in the water and the need for oxygen increases and results in an increase in the BOD value (Egemen and Sunlu, 1996). Due to the high organic pollution in the Ankara Stream (Station 4 and 5), high amount of biochemical oxygen is needed, that causes the BOD values to be high at these points (Figure 6).

Similarly, COD is also a parameter that is high in organic matter-rich waters. For this reason, while it remained within the limits at stations 1, 2 and 3, where organic components were low, COD reached very high values up to 331 mg/L (around 13-fold of EQS value) at stations 4 and 5 (Figure 7). Station 4 and 5 evidently do not have aeration capacity with the high load of organic matter.

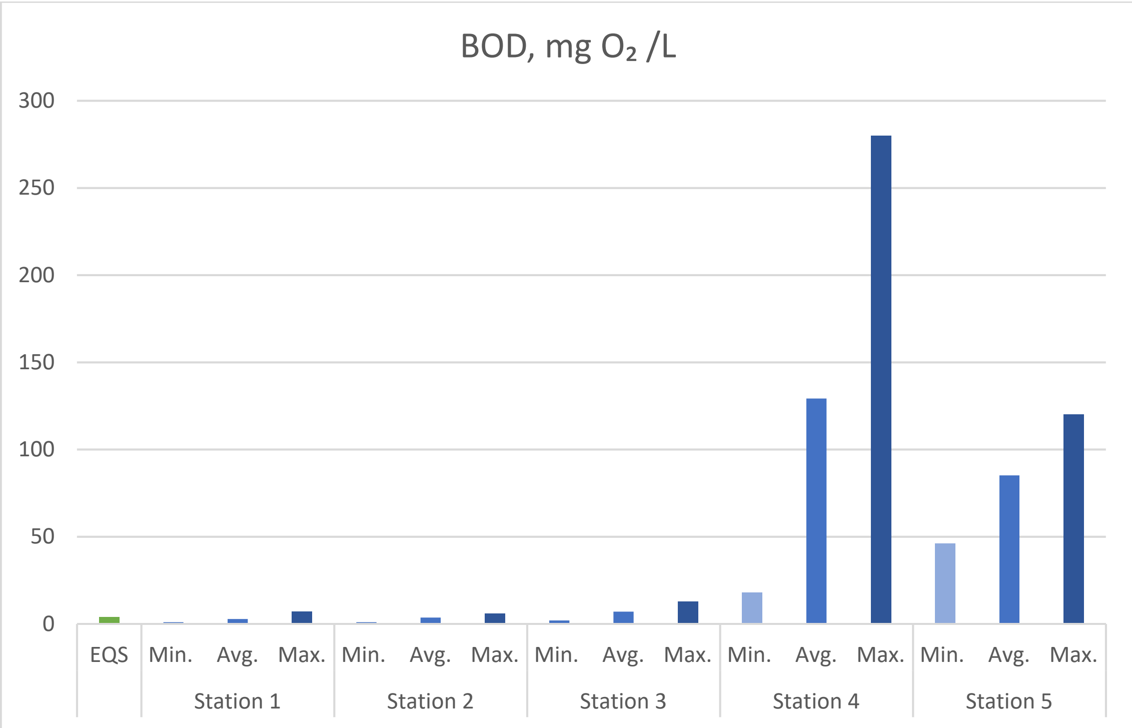

Figure 6. EQS value with respect to minimum, maximum and average BOD values of sampling stations

BOD: COD ratio also used as indicator of pollution in freshwaters. BOD is the oxygen consumption amount by organisms for decomposition of organic matter where COD is the amount of oxygen required for chemical oxidation of total organic matter in water. Thus, COD is always higher than BOD for a water sample. The results also show this relationship, with a changing ratio depending on the quality of water.

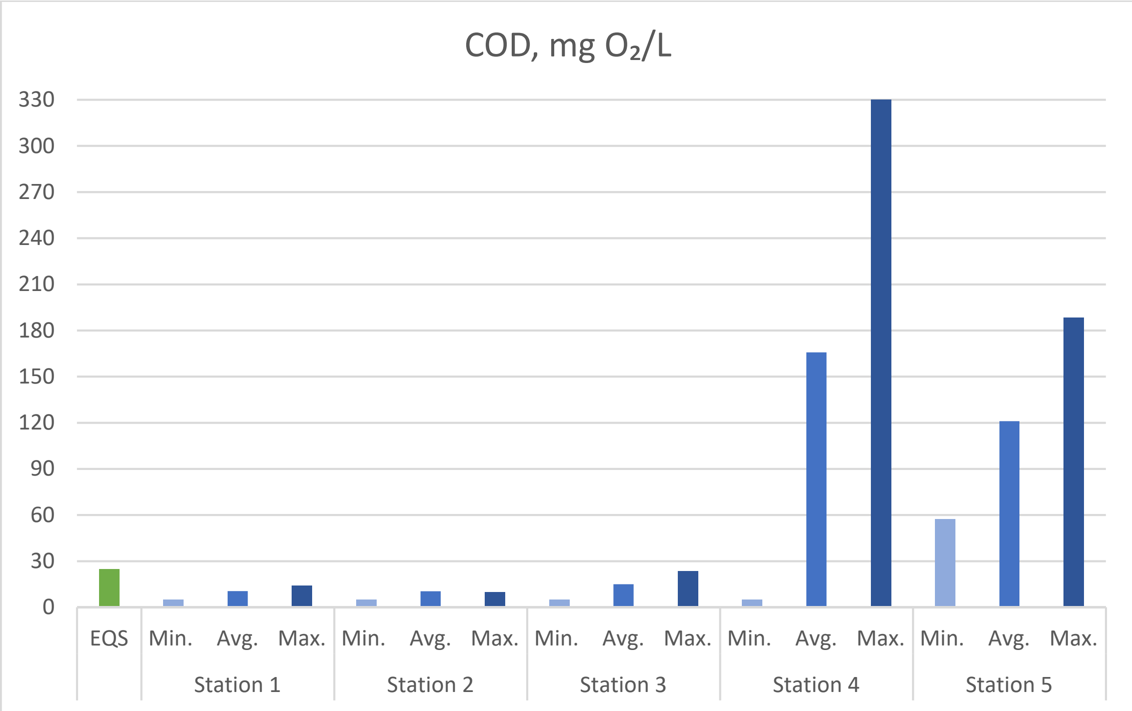

Figure 7. EQS value with respect to minimum, maximum and average COD values of sampling stations

4.1.3. Nitrogen

Another parameter used for the evaluation of pollution is Nitrogen (N). Nitrogen comes mostly from nitrite, nitrate and ammonium (Florescu et al., 2011).

It is known that nitrate values rise to very high concentrations in freshwaters, especially in rural areas with livestock activities and intensive agricultural activities where high amount of fertilizers are used (Rajmohan and Elango, 2005). High concentrations of ammonium are also due to domestic and industrial wastewater and excess fertilizers. Nitrite is also found in nitrogen cycle and is a very important parameter studied in water quality studies. In drinking water, TS266 (2005) reported the upper limit of the nitrite parameter as 0.5 mg/L.

In the following figures (Figure 8-9-10-11) high N in water can be observed. For Station 1 higher N coming from nitrate has a higher influence on total Nitrogen (TN) whereas for Station 4 and 5 ammonium and total Kjeldahl N (the summation of organic and ammonia N) are more influencing source for TN. As can be seen in the figures, TN amount reaches up to 40 mg/L showing the high deterioration limit on this natural water source.

Elevated levels of TN are generally associated with the sewage coming from households. The highest values reach up to 34.54 mg/L at the downstream of the river after passing the highly populated Ankara city.

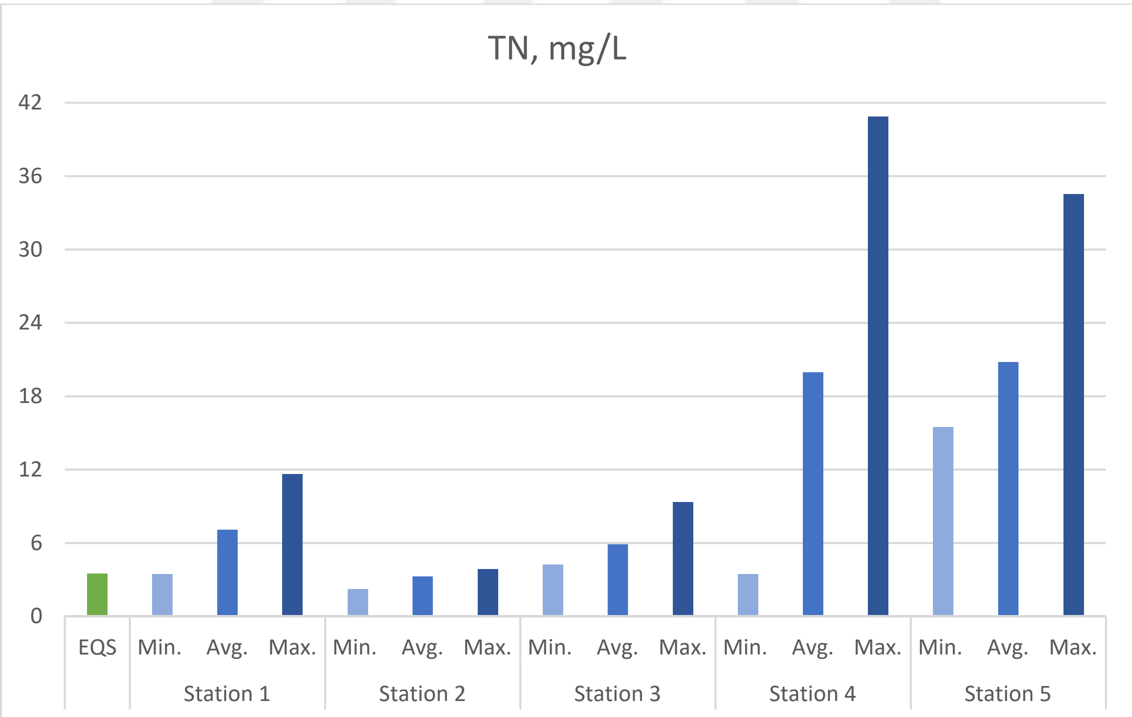

Figure 8. EQS value with respect to minimum, maximum and average Total Nitrogen (TN) values of sampling stations

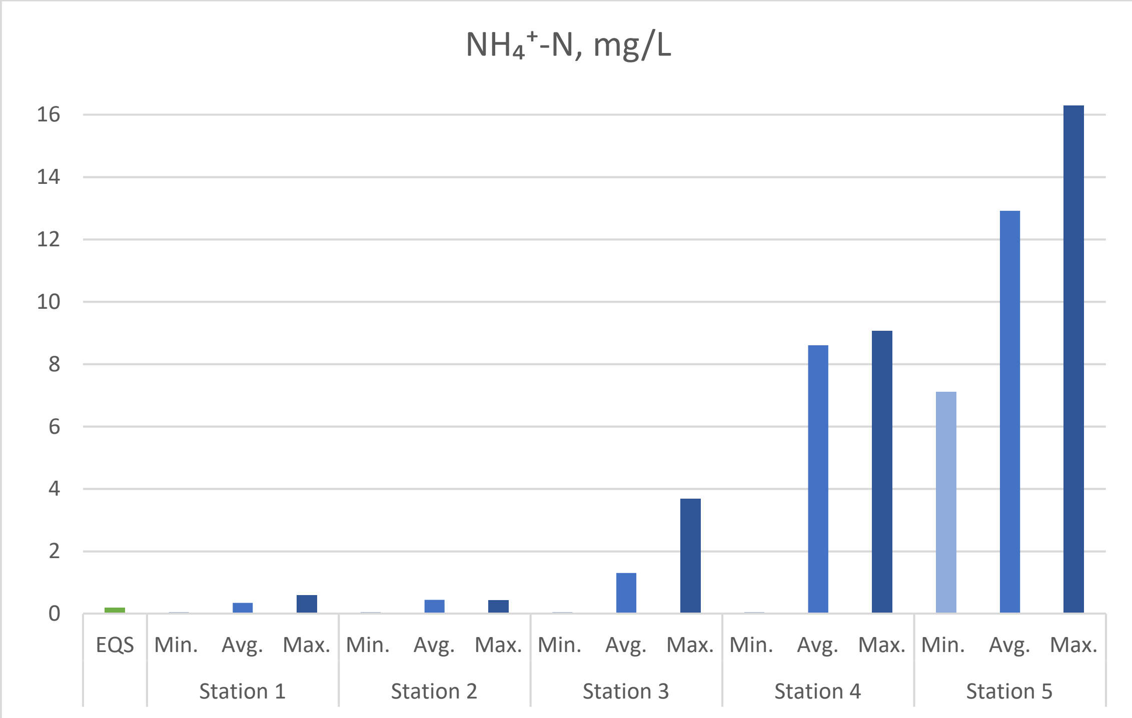

Figure 9. EQS value with respect to minimum, maximum and average NH_4 N values of sampling stations

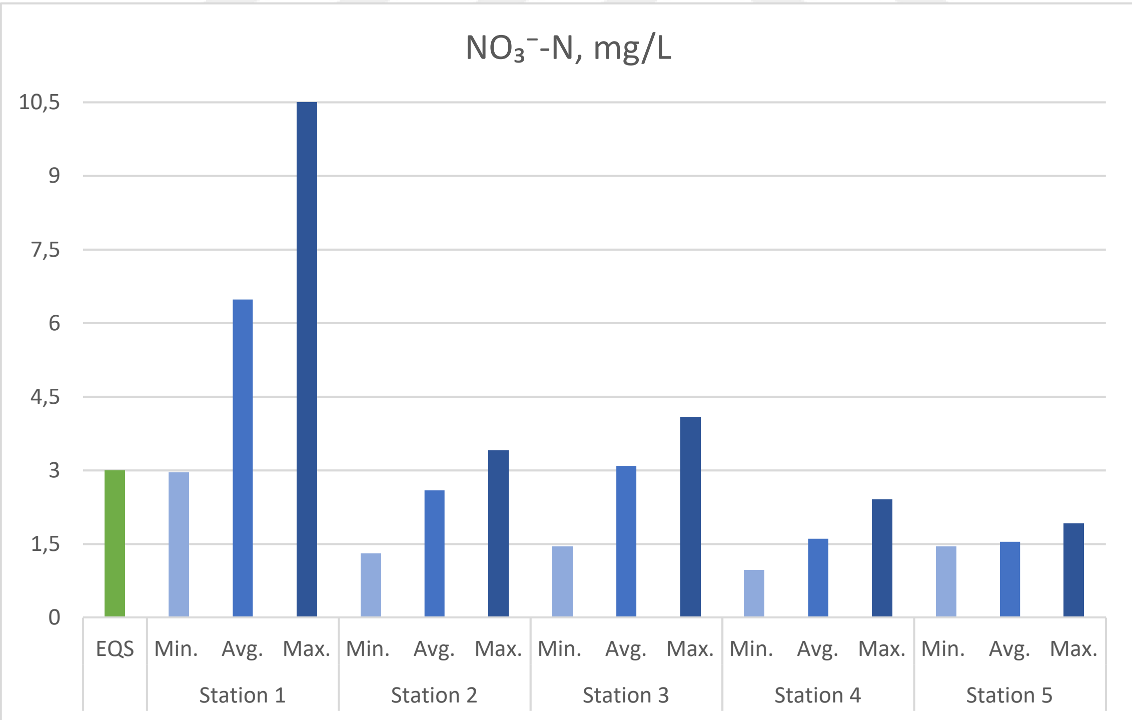

Figure 10. EQS value with respect to minimum, maximum and average NO_3 N values of sampling stations

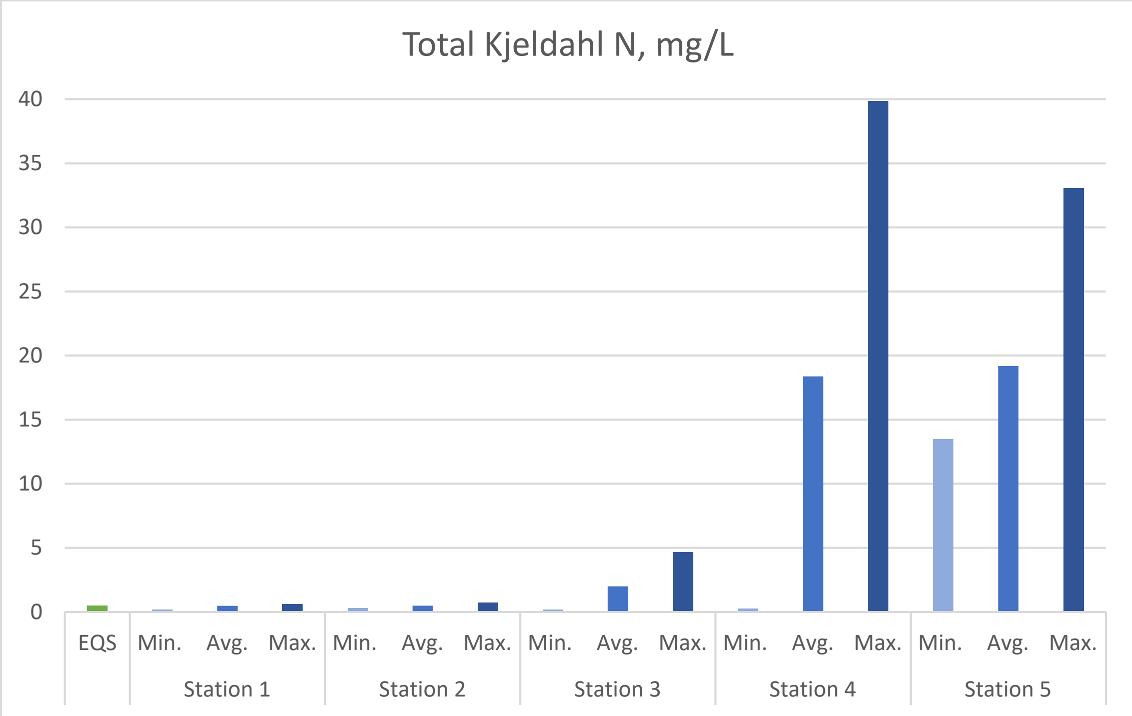

Figure 11. EQS value with respect to minimum, maximum and average Total Kjeldahl N values of sampling stations

4.1.4. Total Phosphorus

The phosphorus value may be high due to the erosion of naturally phosphorus-rich beds in the river. Another source of phosphorus may be the decomposition of organic matter. Other sources of phosphorus from human activities can be listed as industrial wastes, agricultural land run-off and water from municipal wastewater plants.

Except for the Station 1, the total phosphorus (TP) results failed with respect to EQS value. According to the Sakarya River Basin Action Plan prepared by TÜBİTAK MAM, due to the high population in the region, Ankara Stream Basin has the highest pollution load when TP has been compared. Ankara Stream Basin had 13 % non-point and 87 %-point TP load (TÜBİTAK MAM, 2014).

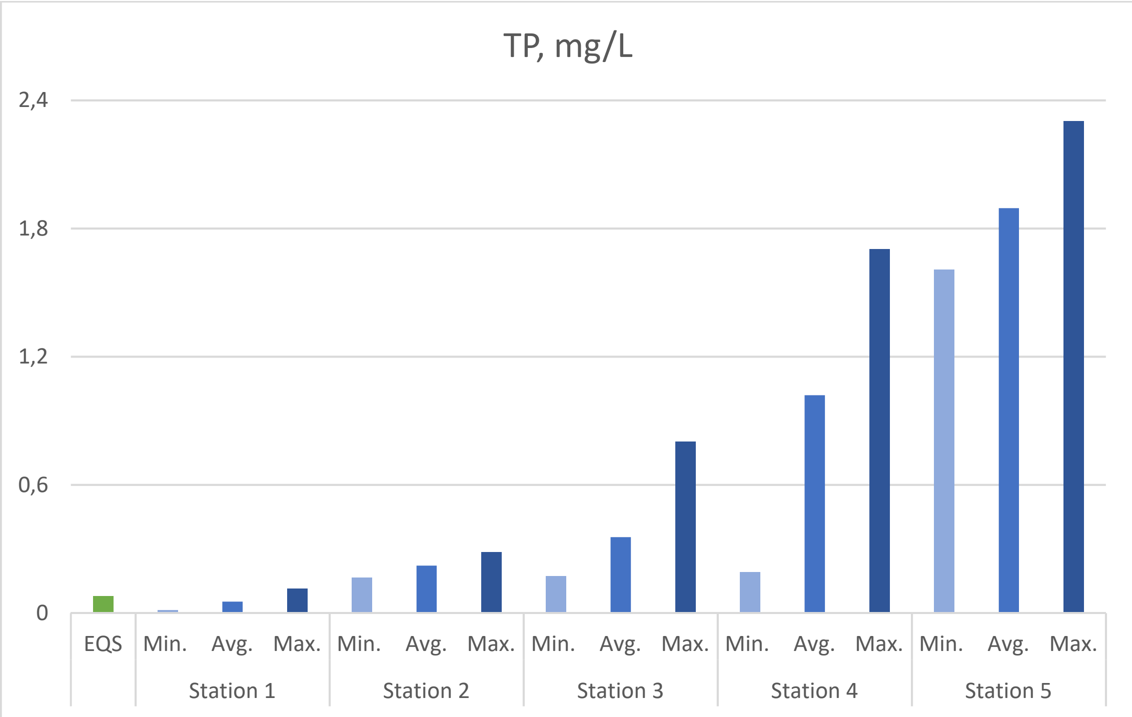

Figure 12. EQS value with respect to minimum, maximum and average Total P values of sampling stations

Station 3, where result showed high TP values, is close to a settlement where agricultural activities are also carried out. High TP values can also be associated with these human-induced activities. For Ankara Stream, after the treatment plant (Station 4 and Station 5) TP content showed a dramatic increase. This may be result of high industrial discharges coming from large organized industrial zones (e.g. OSTİM and İvedik) and the treated municipal water discharges which are rich in detergents. These points are located downstream of the densely populated area on the river.

When the TP and TN parameters are found in high amounts in a water body, the risk of eutrophication increases. Therefore, these parameters are taken into account in the determination of sensitive areas. For Station 4 and Station 5, both parameters show high values revealing that Tatlar Wastewater Treatment Plant is unable to reduce these pollutants.

4.1.5. Other Parameters

In total, 26 parameters are used in the calculation of CCME-WQI. Apart from the parameters mentioned above pH, SO_4, Fl, Cl, Na, K, Se, Cd, Ni, An, As, Cu, Ba, Zn and Co are the other parameters that are used in water quality assessment.

pH is expected to be between 6.5 and 9.5 in natural sources. The pH values of all the points we examined for the Ankara Stream Basin were within this range.

For Station 1, sulfate and chlorine concentrations were very high. Station 1 is located at the junction with Kızılırmak and the sulphate and chlorine values may have been high accordingly. As stated in the research of Evcimen and Tiğrek, although an attempt is made to use Kızılırmak for drinking water purposes, high chlorine and sulfate cannot yield results in accordance with the drinking water standard specified in TS 266 (Evcimen and Tiğrek, 2011).

Heavy metals can be poisonous for humans and other organisms even in the low amounts (Qu et al., 2011). Hence it is essential to take heavy metals into account while determining the water quality status. For example, in Figure 13, extremely high amount of Al with up to 6000 µg/L can be seen for Station 4 and 5. The high level of heavy metals, such as Al, can be mainly caused by the discharges from industrial activities which are extensive in the region.

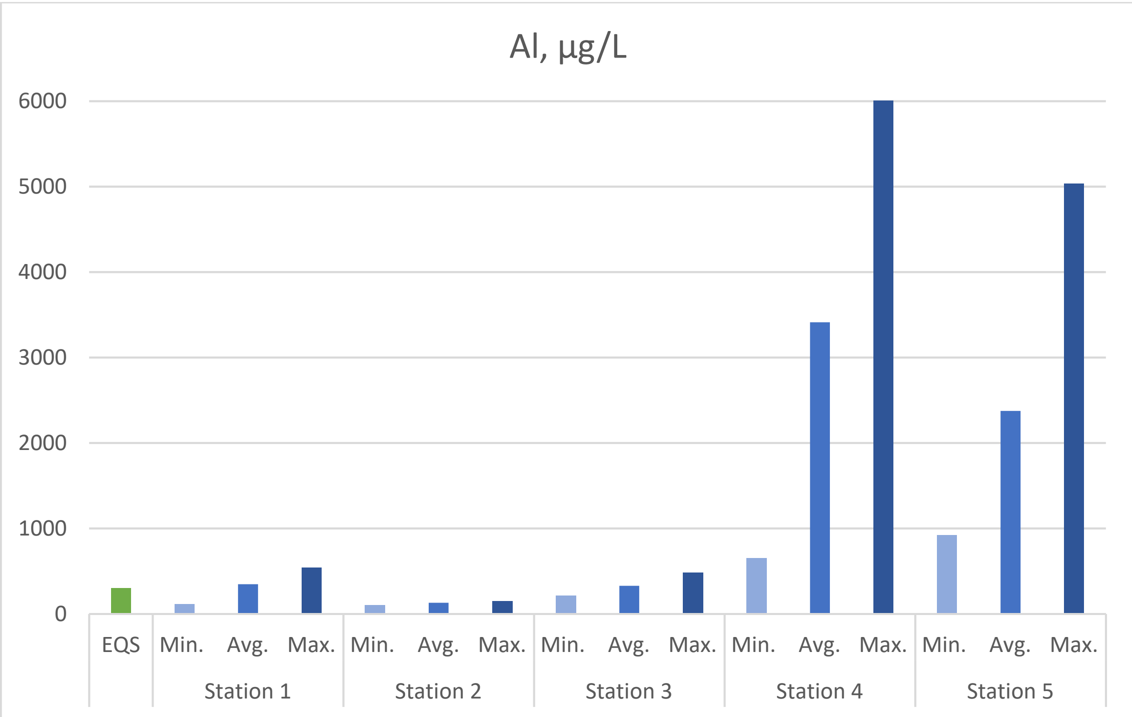

Figure 13. EQS value with respect to minimum, maximum and average Al values of sampling stations

4.2. CCME-WQI

The results of water quality index calculations are shown in Table 6. According to the table, water quality status of Station 1, Station 2, Station 3, Station 4, Station 5 are found to be Marginal, Fair, Fair, Poor and Poor respectively.

Table 6. Factors and overall water quality values for stations.

	F1	F2	F3	Overall	Status
Station 1	61.53846	31.66667	31.45197	56.10875	Marginal
Station 2	34.61538	17.80822	11.36856	76.58563	Fair
Station 3	42.30769	25.83333	29.94161	66.5635	Fair
Station 4	57.69231	42.5	86.1426	35.30601	Poor
Station 5	50	45.83333	87.44828	36.10265	Poor

Classical Activated Sludge Process is used in this biggest Wastewater Treatment Plant of Turkey which has a daily treatment capacity of 765000 m^3 (ASKİ, 2020). Although it is planned to be revised in 2025 with approximately 6 million population equivalent and 1,377,000 m3/day wastewater treatment capacity, the plant does not remove N and P now (TÜBİTAK MAM, 2014). Thus, TN and TP parameters are found to be very high at stations 4 and 5 worsening the quality status for both points.

Station 2 is found in a protected area and CCME-WQI score for this station is found to be 76.59 referring to Fair quality status. This is the best quality of the sampling stations. Water and natural ecosystem are protected by taking various precautions in this region, which is designated as a protected area because it has drinking and utility water resources.

The region is a sensitive area from which surface freshwaters are intended to provide drinking water. In sensitive areas anthropogenic effect is tried to be minimized because if no precautions are taken water may contain high nitrate concentrations (Bütünoğlu, 2018). At this point where human influence has been reduced, it is realistic for the water status to be better than other points.

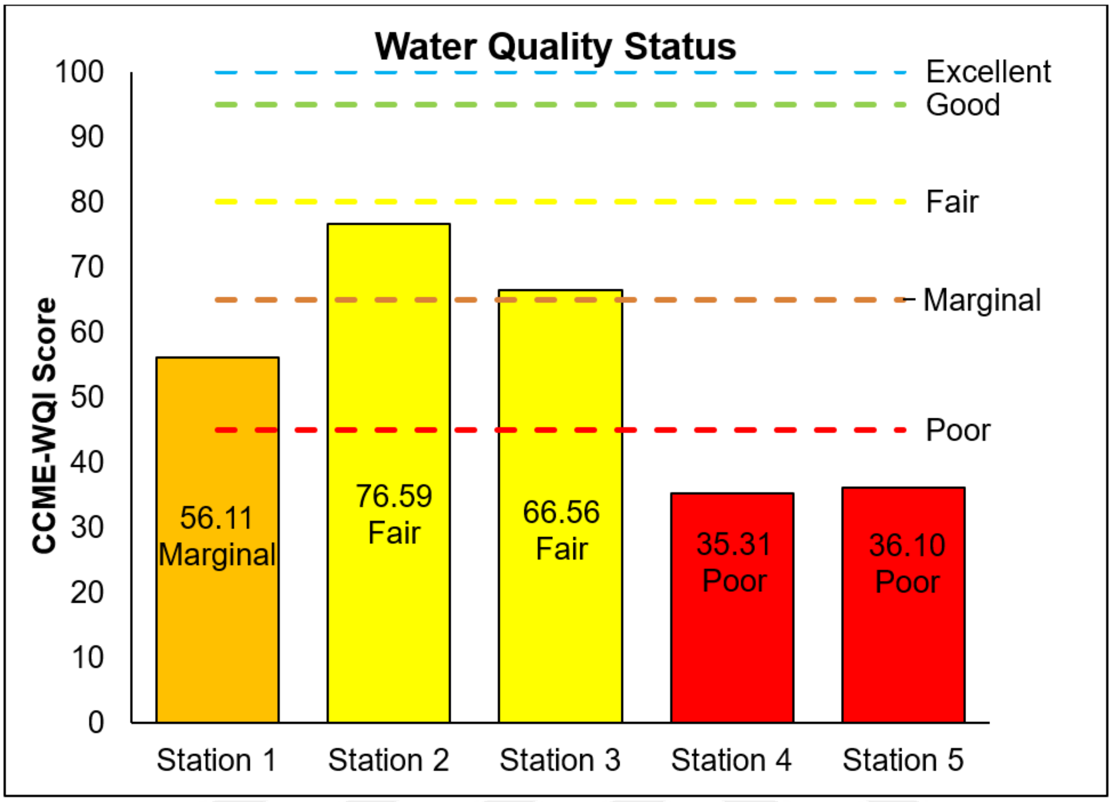

Figure 14. The color-coded water quality status for sampling stations in accordance with CCME-WQI scores

The index, which has been applied to chemical monitoring data, gives a general judgment by giving equal weight to all parameters. In Table 7, the CCME-WQI results are compared with RSWQM quality classes. These can be interpreted that the quality classes give similar results according to the regulation classification (Official Gazette, 2012). According to the regulation, 3 quality classes have been determined. Parameters marked as I. Class (Very good), II. Class (Good) and III. Class (Medium). In Table 7 yellow color represents the lowest quality within the specified limits.

In this comparison, it is possible to see the differences between CCME-WQI and RSWQM arranged in accordance with WFD criteria. First of all, it should be noted that RSWQM cannot reveal a single status for a point, instead, a separate water class can be determined for each parameter. While RSWQM evaluates water quality with 3 quality classes, CCME-WQI gives more detailed results with 5 water quality categories. CCME-WQI gave similar but more detailed results to RSWQM for points located in the Ankara River basin.

According to the regulation, in estimating the water quality class of a station, the values with the worst measurement are included to determine the effect of the pollutant source. In this study, every point used is classified as III. Class water according to this principle. However, when parameters are examined individually, the most polluted points are found to be Station 4 and Station 5. The CCME-WQI results at these stations were also Poor status, which indicates the worst case of this index.

- At Station 1, Quality Classes I and II are more intense in results according to RSWQM. CCME-WQI gave results as Marginal.
- At Station 2, Quality Classes I and II are more intense in results according to RSWQM. CCME-WQI gave results as Fair.
- At Station 3, Quality Classes I and II are more intense in results according to RSWQM. CCME-WQI gave results as Fair.
- At Station 4 Quality Classes II and III are more intense in results according to RSWQM. CCME-WQI gave results as Poor.
- At Station 5, Quality Class III is more intense in results according to RSWQM. CCME-WQI gave results as Poor.

When these results are compared with the past quality status of the river, it has been seen that results compatible with Durmuş's study were obtained (Durmuş, 2021). It has been observed that the pollution status of the points located on the Ankara Stream is very high, similar to the results obtained in the earlier periods (Kazancı and Girgin, 1998; Atıcı and Ahıska, 2005).

Table 7. Water quality classes in accordance with RSWQM given with CCME-WQI results for five stations*

Date	Feb. 2019	May 2019	Aug. 2019	Nov. 2019	Feb. 2020	Feb. 2019	May 2019	Feb. 2020	Feb. 2019	May 2019	Aug. 2019	Nov. 2019	Feb. 2020	Feb. 2019	May 2019	Aug. 2019	Nov. 2019	Feb. 2020	Feb. 2019	May 2019	Aug. 2019	Nov. 2019	Feb. 2020	Water Quality Classes		
	Station 1					Station 2			Station 3					Station 4					Station 5					I	II	III
CCME-WQI RESULTS	MARGINAL					FAIR			FAIR					POOR					POOR					very good	good	medium
pH	8,40	8,04	8,04	8,37	8,75	8,10	7,87	7,95	8,00	7,93	7,53	7,96	7,96	7,50	7,35	7,82	7,66	7,38	7,50	7,68	7,59	7,60	7,53	6-9	6-9	6-9
EC (µS/cm)	2070,00	334,00	458,00	440,00	235,00	771,00	89,40	184,00	943,00	920,00	1395,00	1164,00	119,00	1340,00	858,00	1522,00	167,00	90,60	1637,00	1330,00	1333,00	136,00	165,00	< 400	1000	> 1000
DO (mg/L)	10,88	10,22	6,87	10,20	9,38	12,29	9,44	10,12	10,80	9,35	4,49	9,10	8,11	5,73	2,57	7,25	5,76	2,36	5,30	4,39	2,48	5,76	3,80	> 8	6	< 6
COD (mg/L)	<5	8,12	14,09	9,09	10,92	<5	10,60	10,21	<5	12,46	23,65	11,36	12,29	62,30		28,98	331,37	240,39	57,27	103,00	108,39	188,35	147,80	< 25	50	> 50
BOD (mg/L)	1,00	2,00	7,00	2,00	2,00	1,00	6,00	4,00	2,00	4,00	11,00	5,00	13,00	48,00	130,00	18,00	280,00	170,00	46,00	70,00	80,00	120,00	110,00	< 4	8	>8
Ammonia N (mg NH_4^+-N/L)	<0,047	<0,047	0,09	0,60	<0,047	<0,047	<0,047	0,44	0,09	<0,047	3,69	<0,047	0,13	8,01	<0,047	<0,47	9,07	8,74	12,99	13,62	7,11	16,29	14,58	< 0,2	1	>1
Nitrate Nitrogen (mg NO_3^--N/L)	5,27	2,96	10,55	10,09	3,54	3,41	1,31	3,06	2,98	3,20	1,46	3,73	4,09	1,44	0,97	2,41	<1,131	<1,130	1,92	1,45	1,46	1,45	1,45	< 3	10	> 10
Total Kjeldahl-N (mg N/L)	0,17	0,46	0,58	0,61	0,55	0,30	0,41	0,73	0,93	3,50	4,64	0,19	0,70	8,39	39,86	0,26	16,76	26,57	13,48	17,19	16,70	33,04	15,51	< 0,5	1,5	> 1,5
Total N (mg N/L)	5,45	3,44	11,65	10,72	4,17	3,73	2,20	3,86	4,71	9,35	6,31	4,23	4,84	9,85	40,85	3,43	17,95	27,74	15,49	18,74	18,21	34,54	17,02	< 3,5	11,5	> 11,5
Total P (mg P/L)	0,01	0,05	0,12	0,06	0,03	0,17	0,29	0,21	0,26	0,35	0,19	0,80	0,17	0,54	1,25	0,19	1,41	1,70	1,64	2,30	1,61	1,95	1,97	< 0,08	0,2	> 0,2
Floride (µg/L)	0,76	0,83	2,16	0,94	0,48	0,36	0,19	0,15	0,36	0,30	0,38	0,17	0,19	0,34	0,36	0,58	0,44	0,37	0,47	0,43	0,46	0,34	0,32	≤ 1000	1500	> 1500
Selenium (µg/L)	4,10	<1,70		3,95	<1,70	1,17		<1,70	<0,60	<0,40		<0,90	<1,70	<0,60	<0,40		12,87	<1,70	2,53	<1,70		2,93	1,67	≤ 10	15	> 15

*The color codes are given according to RSWQM for this table, not for the CCME-WQI color codes

Table 8. Water quality classes in accordance with RSWQM (before 2021 revision) given with CCME-WQI results for five stations*

Date	Feb. 2019	May.19	Aug. 2019	Nov. 2019	Feb. 2020	Feb. 2019	May.19	Feb. 2020	Feb. 2019	May.19	Aug. 2019	Nov. 2019	Feb. 2020	Feb. 2019	May.19	Aug. 2019	Nov. 2019	Feb. 2020	Feb. 2019	May.19	Aug. 2019	Nov. 2019	Feb. 2020	Water Quality Classes			
	Station 1					Station 2			Station 3					Station 4					Station 5					I	II	III	III
CCME-WQI RESULTS	MARGINAL					FAIR			FAIR					POOR					POOR					very good	good	medium	poor
pH	8,4	8,04	8,04	8,37	8,75	8,1	7,87	7,95	8	7,93	7,53	7,96	7,96	7,5	7,35	7,82	7,66	7,38	7,5	7,68	7,59	7,6	7,53	6,5-8,5	6,5-8,5	6,0-9,0	out of 6,0-9,0
EC (µS/cm)	2070	334	458	440	235	771	89,4	184	943	920	1395	1164	119	1340	858	1522	167	90,6	1637	1330	1333	136	165	< 400	400-1000	1001-3000	> 3000
DO (mg/L)	10,88	10,22	6,87	10,2	9,38	12,29	9,44	10,12	10,8	9,35	4,49	9,1	8,11	5,73	2,57	7,25	5,76	2,36	5,3	4,39	2,48	5,76	3,8	> 8	6-8	3-6	< 3
COD (mg/L)	<5	8,12	14,09	9,09	10,92	<5	10,6	10,21	<5	12,46	23,65	11,36	12,29	62,3		28,98	331,4	240,4	57,27	103	108,4	188,4	147,8	< 25	50	70	> 70
BOD (mg/L)	1	2	7	2	2	1	6	4	2	4	11	5	13	48	130	18	280	170	46	70	80	120	110	< 4	8	20	>20
Amonium N (mg NH_4^+-N/L)	<0,047	<0,047	0,094	0,598	<0,047	<0,047	<0,047	0,444	0,091	<0,047	3,693	<0,047	0,129	8,006	<0,047	<0,47	9,07	8,737	12,99	13,62	7,109	16,29	14,58	< 0,2	0,2-1	1-2	> 2
Nitrate Nitrogen (mg NO_3^--N/L)	5,265	2,959	10,55	10,09	3,543	3,413	1,314	3,055	2,979	3,2	1,457	3,734	4,091	1,441	0,969	2,414	<1,131	<1,130	1,92	1,449	1,455	1,449	1,448	< 5	5-10	10-20	> 20
Total Kjeldahl-N (mg N/L)	0,17	0,46	0,58	0,61	0,55	0,3	0,41	0,73	0,93	3,5	4,64	0,19	0,7	8,39	39,86	0,26	16,76	26,57	13,48	17,19	16,7	33,04	15,51	< 0,5	1,5	5	> 5
Total P (mg P/L)	0,014	0,049	0,115	0,059	0,032	0,166	0,287	0,213	0,263	0,349	0,189	0,802	0,172	0,542	1,254	0,193	1,406	1,703	1,643	2,303	1,607	1,954	1,97	< 0,03	0,03-0,16	0,16-0,65	> 0,65
Floride (µg/L)	0,76	0,83	2,16	0,94	0,48	0,36	0,19	0,15	0,36	0,3	0,38	0,17	0,19	0,34	0,36	0,58	0,44	0,37	0,47	0,43	0,46	0,34	0,32	≤ 1	1,5	2	> 2
Selenium (µg/L)	4,1	<1,70		3,95	<1,70	1,17		<1,70	<0,60	<0,40		<0,90	<1,70	<0,60	<0,40		12,87	<1,70	2,53	<1,70		2,93	1,67	≤ 10	10	20	> 20

*The color codes are given according to RSWQM (before 2021 revision) for this table, not for the CCME-WQI color codes

Table 8 gives the water quality classification according to the RSWQM before revision in 2021. This four level classification is superseded by three level classification and is not valid anymore. The four quality classes were “Very good”, “Good”, “Medium” and “Poor” in regulation, and the results are more consistent with CCME-WQI results.

- For Station 1, 2 and 3, Quality Class I is more intense according to old version of RSWQM where CCME-WQI gave results as Marginal, Fair and Fair respectively.
- For Station 4 and 5 Quality Class IV is more intense according to old version of RSWQM where CCME-WQI gave results as Poor and Poor for both points.

5. CONCLUSION

CCME-WQI was applied to water quality parameters for five stations in Ankara Stream Sub-Basin in Sakarya River Basin. The results are compared with the RSWQM water quality classes of these five stations. However, the regulation proposes three quality classes (I, II and III) where CCME-WQI has five classes (Excellent, Good, Fair, Marginal, Poor). RSWQM, which is prepared to meet the requirements of EU- WFD, can define the waters with 'good status' with Classes I and II and leave all other waters at Class III. However, it is also important to know how far the waters are from being in 'good condition' so that corrective actions can be planned and implemented more accurately. Therefore, CCME-WQI, which can provide more detailed results, is a more useful tool for monitoring water bodies.

When the results of CCME-WQI were compared to the results of RSWQM quality classes, three stations showed better quality. The results are Marginal, Fair and Fair according to CCME-WQI and Classes I and II for most of the parameters according to RSWQM. Other two stations from Ankara Stream, which are located after Tatlar Wastewater Treatment Plant, are found to be more polluted for both methods. In the plant, advanced treatment on nitrogen and phosphorus is necessary in order to reduce the high TP and TN values and increse the quality of water.

In our country, research on WQIs have increased recently aiming to find the most suitable method for the water management method applied. With this study, it is shown that CCME-WQI can be used that can give fast and reliable water quality status estimation for regulatory purposes. However, for increased reliability of the method further studies with other water sources are necessary.

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ABSTRACT

Master's Thesis

THE USE OF WATER QUALITY INDEX FOR THE ESTIMATION OF WATER QUALITY IN ANKARA STREAM

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River basin-based approaches, which are based on the ecological structure are applied to the management of water resources throughout the world. Turkey started to implement this approach with the European Union Water Framework Directive. One of the 25 basins determined in this context is the Sakarya River Basin. Ankara Stream sub-basin located in Sakarya River Basin is also a region under high pollution pressure. Factors such as population density and industrialization in the region put great pressure on Ankara Stream passing through city center. Measuring the quality of these water resources is important for taking the necessary steps according to the results obtained.

In order to determine the water quality, large-scale monitoring studies are carried out on water resources. As a result of monitoring activities, high number of data is obtained. These data reveal a clearer and simpler water situation with the help of water quality indices. The Canadian Ministry of Environment Council-Water Quality Index (CCME-WQI) is one of the most widely used indexes in the world.

In this study, it is aimed to use water quality index for the assessment of water quality of the Ankara Stream Basin. Water quality was estimated by CCME-WQI calculation using data for five selected stations from Ankara Stream basin produced by DSI laboratories between February 2019 and February 2020. According to the results of the calculations, it was found to be marginal status for Station 1 and fair for Station 2 and 3 on the rivers connecting to Ankara Stream, while it was poor for Station 4 and Station 5 on the Ankara Stream. It has been found that the results obtained are consistent with the surface water regulation water quality classes and therefore reflect the real state of the water. It is thought that this index can be used by decision makers because it can accurately show the general condition of water.

Keywords: Ankara Stream, water quality, Water Framework Directive, Canadian Water Quality Index

ÖZET

Yüksek Lisans Tezi

ANKARA ÇAYI'NDA SU KALİTESİNİN TAHMİNİNDE SU KALİTE İNDEKSİ KULLANIMI

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Dünya genelinde su kaynaklarının yönetimi konusunda uygulanan, ekolojik yapıyı temel alan nehir havza bazlı yaklaşımlar Türkiye'de de Avrupa Birliği Su Çerçeve Direktifi ile uygulanmaya başlanmıştır. Bu kapsamda belirlenen 25 havzadan birisi de Sakarya Nehir Havzası'dır. Sakarya Nehir Havzası'nda yer alan Ankara Çayı Alt Havzası da yüksek kirlilik baskısı altında olan bir bölgedir. Bölgedeki nüfus yoğunluğu ve sanayileşme gibi faktörler, şehir merkezinden geçen Ankara Çayı ve çevresindeki diğer akarsular için büyük baskı oluşturmaktadır. Bu su kaynaklarının kalitesinin ölçülmesi, elde edilen sonuçlara göre gerekli adımların atılması için önem taşımaktadır.

Su kalitesinin belirlenebilmesi için su kaynakları üzerinde planlı ve geniş çaplı izleme çalışmaları yapılmaktadır. İzleme faaliyetleri sonucunda yüksek miktarda veri elde edilir. Bu veriler, su kalitesi indeksleri yardımı ile daha anlaşılır ve sade bir su durumu ortaya koyar. Kanada Çevre Bakanlığı Konseyi-Su Kalite İndeksi (CCME-WQI) de dünyada en yaygın olarak kullanılan indekslerden biridir.

Bu çalışmada, Ankara Çayı Havzası'nda belirlenmiş beş istasyon için su kalite indeksi metodu ile su kalitesi tahmini yapılmıştır. Şubat 2019 ile Şubat 2020 tarihleri arasında DSİ laboratuvarları tarafından üretilmiş veriler kullanılarak CCME-WQI hesaplaması ile su kalitesi tahmin edilmiştir. Hesaplama sonuçlarına göre, Ankara Çayı'na bağlanan akarsular üzerindeki İstasyon 1, İstasyon 2 ve İstasyon 3 için sırasıyla zayıf, orta ve orta çıkarken Ankara Çayı üzerindeki İstasyon 4 ve İstasyon 5 için kötü kalitede olduğu bulunmuştur. Elde edilen sonuçların yüzeysel sular yönetmeliği su kalite sınıfları ile tutarlı olduğu görülmüştür ve bu nedenle suyun gerçek durumunu yansıtmaktadır. Suyun genel durumunu gösterebilmesi nedeniyle bu indeksin karar alıcılar tarafından kullanılması önerilir.

Anahtar Kelimeler: Ankara Çayı, su kalitesi, Su Çerçeve Direktifi, Kanada Su Kalite İndeksi