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Evaluation of surface water quality in the Southern Marmara Agricultural Basin

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Abstract

The Southern Marmara Agricultural Basin (SMAB) is a strategic region located in the northwest of Turkey, covering a significant portion of the Marmara Region. Rich in agriculture, industry, tourism, and water resources, this basin is one of the critical areas that must be protected and managed in line with Turkey's sustainable development goals. Due to its strategic importance, the basin is exposed to multiple diffuse pollution sources, which pose significant environmental challenges.Therefore, the protection and implementation of sustainable management strategies for the basin are of great importance. In this study, the current water quality was evaluated according to the Surface Water Quality Regulation using samples taken from points where diffuse pollutant sources are dense in the basin. Additionally, correlation matrices were created to examine the relationships between water quality parameters. The study results revealed significantly high concentrations of total nitrogen (TN) and total phosphorus (TP) at the sampling points, indicating substantial nutrient loading. Moreover, the high correlation coefficients between pollutants increase the likelihood that pollution is reaching the receiving environment from non-point (diffuse) sources. These findings indicate that TN and TP loads significantly impact water quality in the SMAB.

Keywords: Southern Marmara Agricultural Basin, Surface Water Quality, Diffuse Pollutant, Basin-Based Water Management

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INTRODUCTION

Considering the demands of the growing global population, the sustainable management of water resources has become an inevitable necessity (Sdiri et al., 2018; Loucks, 2000). In this context, the preservation of both the quantity and quality of water is of vital importance, especially in regions where industrialization is accelerating. To mitigate the pressure of population growth and industrial activities on water resources, it is essential to adopt comprehensive and effective strategies for their protection and management (Rezaee et al., 2021; Dawadi et al., 2013). Additionally, the increasing global threats such as climate change further complicate the management of water resources, necessitating the development of management strategies to protect these resources effectively (Wang et al., 2016; Elgendy et al., 2024; Sivakumar, 2011). Therefore, sustainable water management practices are critically important to meet the needs of current generations and to leave healthy ecosystems for future generations. In this regard, policymakers, environmental scientists, and all relevant stakeholders must collaborate to develop effective solutions.

In this context, basin-based sustainable water management approaches are of strategic importance for the integrated management and protection of water resources. Basin-based management allows for the assessment of water resources according to various usage scenarios and enables the implementation of necessary measures to minimize potential adverse effects on water quality (Pitt and Clark, 2008; Santhi et al., 2006, Randhir et al., 2001). Additionally, this method supports the natural structure and hydrological cycle of basins, contributing to the healthy functioning of ecosystems.

Pollution in basins primarily consists of two categories: point source pollution and non-point source (diffuse) pollution (Huang et al., 2015). Point source pollution is typically caused by municipal discharges or factories, making it easier to identify and manage the pollutant at its source (Xueyong and Chaohai, 2010; Zessner and Lindtner, 2005). Non-point source pollution, on the other hand, originates from livestock, agriculture, unregulated dumping sites, or septic system effluents (Wang et al., 2021). This type of pollution can lead to the accumulation of essential nutrients such as phosphorus and nitrogen in water resources, which can have significant ecological impacts. Agricultural activities, particularly those involving fertilization and pesticide use, play a crucial role in the formation of non-point source pollution (Basnyat et al., 2000). The transport of diffuse pollutants depends on climate, meteorological conditions, geographic, and geological factors, and reaches receiving environments through transformation reactions and complex transport processes (Haksevenler Gürsoy and Ayaz, 2021).

Unlike point source pollution, identifying and controlling non-point source pollution is considerably more challenging due to its widespread and diffuse nature. This is because such pollution sources are spread over a large geographical area and originate from numerous sources that are difficult to detect rather than a specific point (Lai et al., 2011). Therefore, combating non-point source pollution is a complex process that requires integrated basin management and multidisciplinary strategies. Within the framework of sustainable water management, methods such as comprehensive monitoring networks, advanced treatment technologies, and effective land use planning should be implemented to mitigate the effects of these pollutants. These approaches are vital for the protection of water resources and for meeting the needs of future generations in a sustainable manner.

Especially in the Southern Marmara Agricultural Basin (SMAB), where industrial and livestock activities are high, identifying pollutants reaching the receiving environment will enable the implementation of necessary measures. From this perspective, the importance of basin-based water quality studies becomes evident. In this study, water quality in the basin was evaluated according to the Surface Water Quality Regulation using samples taken from points where non-point source pollutants are predominant. Additionally, water quality parameters were analyzed by creating correlation matrices, and the relationships between these parameters were examined to identify sources of water pollution.

MATERIALS AND METHODS

Study Area

The SMAB is a large area located in the northwest region of Turkiye, south of the Sea of Marmara, encompassing specific districts within the provinces of Balıkesir, Bilecik, Bursa, Çanakkale, Istanbul, Kocaeli, Sakarya, and Yalova. This geographical region holds a strategic position and includes some of Turkiye's significant agricultural, industrial, and commercial centers (MBIH, 2019).

The SMAB has a complex topography, characterized by coastal plains, fertile valleys, high mountains, and significant water resources. The region is also an area of interaction between various climate types; while the coastal areas experience a typical Mediterranean climate, inland areas are dominated by continental climate characteristics. This geographical and climatic diversity of the study area allows for a wide range of agricultural products. Consequently, the region plays a crucial role in agricultural production and export both within Turkiye and internationally. Due to its location, the basin is highly sensitive to various diffuse and point source pollution sources (Figure 1). Additionally, the basin encompasses 8 provinces and 54 districts in Turkiye, where population density and agricultural and livestock activities are highly prevalent (T.R. MoFA, 2024) (Table 1).

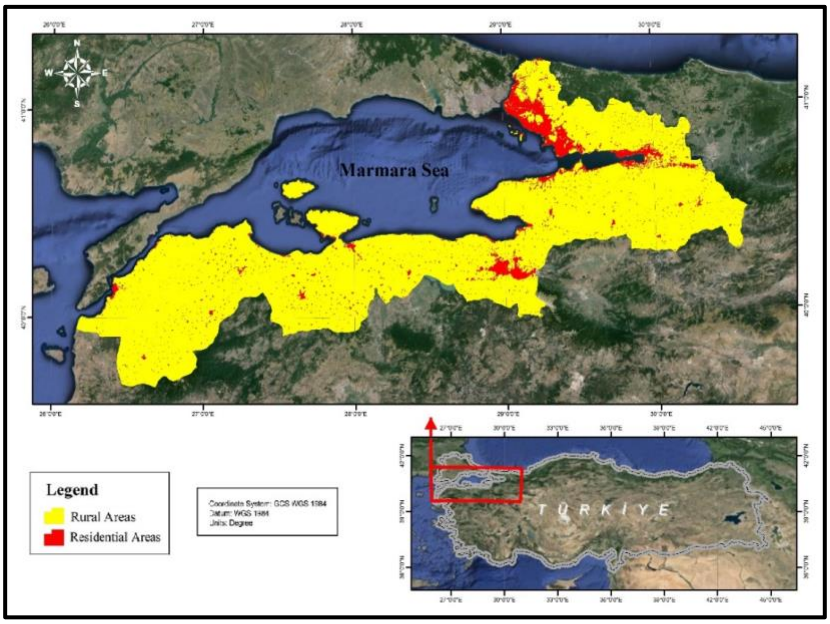

Figure 1. Boundaries of the SMAB

Table 1. Provinces and Districts within the Boundaries of the SMAB (T.R. MoFA, 2024)

Province	District
Balıkesir	Bandırma, Erdek, Gönen, Manyas, Marmara
Bilecik	Osmaneli
Bursa	Gemlik, Gürsu, Iznik, Karacabey, Mudanya, Nilüfer, Orhangazi, Osmangazi, Yıldırım
Çanakkale	Bayramiç, Biga, Çan, Lâpseki, Merkez
Istanbul	Adalar, Ataşehir, Beykoz, Çekmeköy, Kadıköy, Kartal, Maltepe, Pendik, Sancaktepe, Sultanbeyli, Tuzla, Ümraniye, Üsküdar
Kocaeli	Başiskele, Çayırova, Darıca, Derince, Dilovası, Gebze, Gölcük, Izmit, Karamürsel, Kartepe, Körfez
Sakarya	Geyve, Pamukova, Sapanca, Taraklı
Yalova	Altınova, Armutlu, Çınarcık, Çiftlikköy, Merkez, Termal

Sampling and Field Studies

In this study, to determine the surface water characteristics of the SMAB, water samples were collected from selected surface water sources. The aim was to assess the pollution level of the basin in terms of water quality parameters. Samples were taken from points where diffuse pollution sources are predominant. The coordinates of the sampling points are provided in Table 2, and satellite images of the sampling locations are shown in Figure 2.

Table 2. Coordinates of the Sampling Points

Sampling Point	Coordinates	
	X	Y
S1	40.29617	28.45861
S2	40.3709	28.48789
S3	39.89744	28.16010
S4	40.730183	29.988439
S5	40.697117	29.990495
S6	40.734987	29.9557

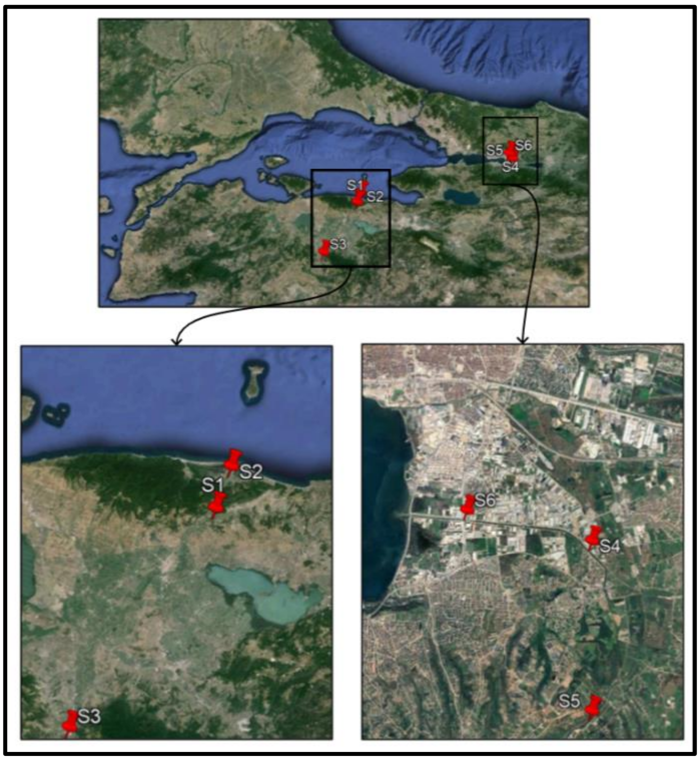

Figure 2. Satellite Images of Sampling Points

The coordinates of S1 represent the Nilüfer Stream. The Nilüfer Stream is exposed to various diffuse pollutants due to anthropogenic factors such as industrialization, intensive agricultural activities, and urban growth. In this region, particularly known for its automotive and textile industries, the stream is polluted by industrial wastes containing heavy metals, organic pollutants, and industrial solvents, agricultural runoff loaded with nutrients like NO_3-N and PO_4-P, and domestic wastewater with high organic matter content. These pollutants degrade aquatic habitats, leading to eutrophication, reducing water quality, and creating toxic effects on aquatic organisms.

The Susurluk Stream (S3) is one of the significant rivers in the Marmara Region. Similar to the Nilüfer Stream, the Susurluk Stream is exposed to various anthropogenic and natural pollution sources due to its location. Intensive agricultural activities in the region lead to the introduction of pesticides into the water, which can cause eutrophication in aquatic ecosystems and threaten biodiversity. Industrial activities also pose a significant pollution threat; industrial wastes from nearby factories and businesses contain chemical pollutants that degrade the stream's water quality. Urban development and growth are additional pollution sources for the Susurluk Stream; urban wastewater and surface runoff carry organic and inorganic substances into the stream. The coordinates of S2 represent the confluence of the Susurluk and Nilüfer Streams before they reach the Marmara Sea. Here, the pollution loads carried by both streams to the Marmara Sea were evaluated.

The coordinates of S4, S5, and S6 represent locations on the Kiraz Stream, which are subject to more urban and industrial diffuse pollution sources compared to other points. The S4 coordinate is situated near various petroleum, food-beverage, and chemical industries. The S5 coordinate is surrounded by farms and agricultural areas. The S6 coordinate represents the point before the Kiraz Stream reaches the Gulf of İzmit. This point was selected to assess the combined pollution loads brought by the S4 and S5 coordinates into the Kiraz Stream.

Surface water samples were taken from each determined point, 30 cm below the stream surface, and the samples were analyzed according to standard methods in an accredited laboratory. The sampling was conducted at points where diffuse pollution sources in the basin are predominant. Images related to the surface water sampling process are provided in Figure 3.

Experimental Measurement

The experiments on surface water samples were conducted in an accredited laboratory in accordance with Standard Methods. Samples were analyzed for Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Total Nitrogen (TN), Nitrate Nitrogen (NO_3^--N), Total Phosphorus (TP), Total Coliform (TC), Fecal Coliform (FC), Potassium (K), Boron (B), Fluoride (F), Selenium (Se), Molybdenum (Mo), Zinc (Zn), Copper (Cu), Manganese (Mn), Iron (Fe), and Sulfide (H_2S-S) parameters. The methods, measurement techniques, and units used in the analysis of the collected samples are summarized in Table 3. The evaluation of the parameters obtained from the water samples was conducted within the framework of the Surface Water Quality Regulation (SWQR) (SWQR, 2021). Annex 5, Table 2 of the regulation specifies the quality criteria for Inland Surface Water Resources based on General Chemical and Physicochemical Parameters. The limit values and water quality classes specified in the regulation are shown in Table 4.

Figure 3. Surface Water Sampling

Table 3. Methods and Units Used in the Analysis of Collected Samples

Parameter	Method Number	Method	Unit
Dissolved Oxygen (DO)	SM 4500 O G	Membrane Electrode Method	mg/L
Chemical Oxygen Demand (COD)	SM 5220 B	Open Reflux-Titrimetric Method	mg/L
Biochemical Oxygen Demand (BOD_5)	SM 5210 B	5-Day BOD Test	mg/L
Total Kjeldahl Nitrogen (TKN)	SM 4500 Norg B	Calculation with Nitrite, Nitrate, and Kjeldahl Nitrogen (Calculation Method)	mg/L
Ammonium Nitrogen (NH_4^+-N)	SM 4500 NH_3 F	Spectrophotometric Method	mg/L
Nitrate Nitrogen (NO_3^--N)	SM 4110 B	Calculation with Nitrite, Nitrate, and Kjeldahl Nitrogen (Calculation Method)	mg/L
Total Nitrogen (TN)	SM 4500 NO_2^- B SM 4110 B SM 4500 Norg B	Calculation with Nitrite, Nitrate, and Kjeldahl Nitrogen (Calculation Method)	mg/L
Total Phosphorus (TP)	EPA 200.7	ICP-OES Method	mg/L
Fecal Coliform (FC)	SM 9222 D	Membrane Filtration Technique	CFU/100 mL
Total Coliform (TC)	SM 9222 B	Membrane Filtration Technique	CFU/100 mL
Potassium (K)	EPA 200.7	ICP-OES Method	mg/L
Boron (B)	EPA 200.7	ICP-OES Method	mg/L
Fluoride (F)	SM 4110 B	IC Method	mg/L
Selenium (Se)	EPA 200.7	ICP-OES Method	mg/L
Molybdenum (Mo)	EPA 200.7	ICP-OES Method	mg/L
Zinc (Zn)	EPA 200.7	ICP-OES Method	mg/L
Copper (Cu)	EPA 200.7	ICP-OES Method	mg/L
Manganese (Mn)	EPA 200.7	ICP-OES Method	mg/L
Iron (Fe)	EPA 200.7	ICP-OES Method	mg/L
Sulfur (H_2S-S)	SM 4500 S^{-2} D	Spectrophotometric Method	mg/L

Assessment for the classification of surface waters has been conducted using the data obtained from monitoring results within the scope of the Regulation on Amendments to the Regulation on Surface Water Quality Management, employing the parameters and criteria specified in Annex-5. The quality classes for the parameter groups in Tables 2 of Annex-5 of this Regulation are indicated by Roman numerals (SWQR, 2021). The classification based on color, according to the standard values in Annex-5, is presented in Table 4.

Pearson Correlation Matrix

The Pearson Correlation Matrix is a statistical method that measures the linear relationship between two variables, with values ranging from -1 to +1. This method is often preferred for analyzing linear relationships between two continuous variables. The Pearson correlation coefficient is particularly used when the data exhibit a bivariate normal distribution. The strength of the correlation increases as the absolute value of the coefficient rises, approaching ±1, indicating an almost perfect linear relationship between the two variables (Schober et al., 2018).

During the calculation of correlation coefficient, sample correlation coefficients obtained for each pair of variables in the data set are used. These coefficients indicate the strength and direction of the linear relationship between the respective variables. The correlation matrix is commonly used in multivariate data analyses; it plays a significant role in methods such as factor analysis and cluster analysis. The components of the matrix include the Pearson correlation coefficients of the respective pairs of variables, and the structure of this matrix varies depending on the characteristics of the data to be analyzed (Hills, 1969).

Table 4. Quality Criteria for Inland Surface Water Resources Based on General Chemical and Physicochemical Parameters (Regulation Amending the Surface Water Quality Regulation, Annex 5 Table 2)

Water Quality Parameter	**Unit**	**Water Quality Classes [(a)]**		
		I	**II**	**III**
Dissolved Oxygen (DO)	mg/L	>8	6	< 6
Chemical Oxygen Demand (COD)	mg/L	< 25	50	>50
Biochemical Oxygen Demand (BOD_5)	mg/L	< 4	8	>8
Total Kjeldahl Nitrogen (TKN) [(b)]	mg/L	< 0.5	1.5	>1.5
Ammonium Nitrogen (NH_4-N)	mg/L	< 0.2	1	>1
Nitrate Nitrogen (NO_3^--N)	mg/L	< 3	10	>10
Total Nitrogen (TN)	mg/L	< 3.5	11.5	>11.5
Total Phosphorus (TP)	mg/L	< 0.08	0.2	>0.2
Fecal Coliform (FC)	CFU/100 mL	-	-	-
Total Coliform (TC)	CFU/100 mL	-	-	-
Potassium (K)	mg/L	-	-	-
Boron (B)	mg/L	-	-	-
Fluoride (F)	mg/L	≤ 1	1.5	>1.5
Selenium (Se)	µg/L	≤ 10	15	>15
Molybdenum (Mo)	mg/L	-	-	-
Zinc (Zn)	µg/L	-	-	-
Copper (Cu)	mg/L	-	-	-
Manganese (Mn)	µg/L	≤ 100	500	>500
Iron (Fe)	µg/L	-	-	-
Sulfur (H_2S-S)	mg/L	≤ 0.002	0.005	>0.005

[(a)] Intended uses of waters according to quality classes:
Class I - High-quality water (Class I water quality indicates "Excellent" water condition);
1) Surface waters with high potential for drinking water,
2) Water that can be used for recreational purposes, including swimming and other body contact activities,
3) Water suitable for trout production,
4) Water suitable for livestock and farm needs,

Class II - Slightly polluted water (Class II water quality indicates "Good" water condition);
1) Surface waters with potential for drinking water,
2) Water suitable for recreational purposes,
3) Water suitable for fish production other than trout,
4) Irrigation water, provided it meets the irrigation water quality criteria determined by current legislation,

Class III - Polluted water (Class III water quality indicates "Moderate" water condition);
Water that can be used for aquaculture and industrial purposes after appropriate treatment, except for facilities requiring high-quality water such as those in the food and textile industries.
(b) TKN: NH_3-N + Organic Nitrogen
(c) TN: TKN + NO_3-N + NO_2-N

RESULTS AND DISCUSSION

Evaluation of Analysis Results

The analysis results of the samples taken from the points whose coordinates are given in Table 2 are presented in Table 5.

When examining S1, it is observed that some pollution parameters of organic origin are at quite high levels. When these pollution parameters are evaluated in terms of general chemical and physicochemical parameters of inland surface water sources, the water sample falls into the I. Class – High-Quality Water category for NO_3^--N and F parameters. However, for the Mn parameter, it is classified as II. Class – Slightly Polluted Water. In contrast, for the parameters COD, BOD_5, TKN, NH_4-N, TN, TP, Se, and SO_4-S, it is categorized as III. Class – Polluted Water.

When evaluated according to the S2 Quality Criteria, the water sample is classified as I. Class – High-Quality Water for NO_3^--N, F, and Mn parameters. However, it is categorized as III. Class – Polluted Water for COD, BOD_5, TKN, NH_4-N, TN, TP, and Se parameters.

For S3, the sample is classified as I. Class – High-Quality Water for NO_3^--N and F parameters. It falls into the II. Class – Slightly Polluted Water category for COD, NH_4-N, TN, and Mn parameters. Nevertheless, it is classified as III. Class – Polluted Water for COD, BOD_5, TP, and Se parameters.

When the water quality parameters of S4 are examined, it is classified as I. Class – High-Quality Water for COD, NH_4-N, NO_3^--N, F, and Mn parameters. However, for the TN parameter, it falls into the II. Class – Slightly Polluted Water category. In contrast, for the COD, BOD_5, and TP parameters, it is categorized as III. Class – Polluted Water.

Table 5. Analysis Results of Water Quality Parameters

Water Quality Parameter	**Unit**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**Water Quality Classes** (a)		
								I	**II**	**III**
Dissolved Oxygen (DO)	mg/L	1.9	5	6.78	8.2	7.09	7.02	>8	6	< 6
Chemical Oxygen Demand (COD)	mg/L	382	78.4	100	123	75	214	< 25	50	>50
Biochemical Oxygen Demand (BOD_5)	mg/L	152.08	31.4	40	49	29.87	85.58	< 4	8	>8
Total Kjeldahl Nitrogen (TKN) (b)	mg/L	20.93	5.27	<5	<5	<5	9.76	< 0.5	1.5	>1.5
Ammonium Nitrogen (NH_4-N)	mg/L	7.31	2.08	0.542	0.194	0.052	4.67	< 0.2	1	>1
Nitrate Nitrogen (NO_3^--N)	mg/L	<0.23	<0.23	1.15	0.95	<0.23	<0.23	< 3	10	>10
Total Nitrogen (TN)	mg/L	23.61	6.68	5.38	<5	<5	12.77	< 3.5	11.5	>11.5
Total Phosphorus (TP)	mg/L	1.043	0.414	0.63	0.335	0.021	0.48	< 0.08	0.2	>0.2
Fecal Coliform (FC)	CFU/100 mL	$22x10^4$	$17x10^3$	$38x10^2$	$9x10^2$	$14x10^2$	$49x10^3$	-	-	-
Total Coliform (TC)	CFU/100 mL	$24x10^4$	$17x10^3$	$39x10^2$	$42x10^3$	$31x10^3$	$62x10^3$	-	-	-
Potassium (K)	mg/L	24.5	8.2	9.2	4.2	1.2	8.3	-	-	-
Boron (B)	mg/L	<1	3.05	4.6	<1	<1	<1	-	-	-
Fluoride (F)	mg/L	<1	<1	<1	<1	<1	<1	≤ 1	1.5	>1.5
Selenium (Se)	µg/L	29.59	17.5	21.4	21.72	28.47	26.96	≤ 10	15	>15
Molybdenum (Mo)	mg/L	<0.01	<0.01	0.021	<0.01	<0.01	<0.01	-	-	-
Zinc (Zn)	µg/L	14.26	<10	<10	<10	<10	<10	-	-	-
Copper (Cu)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.013	-	-	-
Manganese (Mn)	µg/L	186.52	22.12	205.38	12.69	20.95	260.54	≤ 100	500	>500
Iron (Fe)	µg/L	321.47	38.49	72.24	54.79	32.63	119.22	-	-	-
Sulfur (H_2S-S)	mg/L	1.363	<0.1	<0.1	<0.1	<0.1	<0.1	≤ 0.002	0.005	>0.005

The water quality parameters of the sample taken from S5 were evaluated. The parameters NO_3^--N, TP, F, and Mn are classified as Class I – High Quality Water. In contrast, the parameters DO, NH_4-N, and TN are identified as Class II – Slightly Polluted Water. Meanwhile, the parameters COD, BOD_5, and Se are classified as Class III – Polluted Water.

Finally, when evaluated according to S6 Quality Criteria, the parameters NO_3^--N and F are categorized as Class I – High Quality Water. The parameters COD and Mn are classified as Class II – Slightly Polluted Water. However, the parameters COD, BOD_5, TKN, NH_4-N, TN, TP, and Se are classified as Class III – Polluted Water.

When the experimental results are assessed comprehensively, it is observed that at all sampling points, the parameters COD, BOD_5, and Se are categorized as Class III – Polluted Water. Consequently, the COD parameter is classified as Class I – High Quality Water at only one of the six sampling points. High concentrations of COD and BOD_5 lead to a reduction in COD levels in aquatic ecosystems (Maddah, 2022). A decrease in COD levels threatens the survival of fish and other aquatic organisms and reduces biodiversity in the ecosystem (Bhat et al., 2022). Additionally, a decline in oxygen levels in water narrows the habitat of aquatic organisms and creates stress. This situation can negatively affect the reproductive and growth processes of particularly sensitive species (Limburg and Casini, 2019). Therefore, maintaining low levels of COD and BOD_5 in water resources is crucial for the protection of aquatic ecosystems and the sustainable management of water resources. Management strategies should be effectively implemented to keep these parameters under control and prevent potential negative environmental effects.

The reason for the high Se, Cu and Mn concentrations at all six sampling points is thought to be due to agricultural runoff. Fertilizers and pesticides used excessively due to agricultural activities can leach into water sources, leading to increased concentrations of Se, Cu, and Mn. These chemicals can be transported to local water sources through agricultural runoff, leading to an increase in the concentrations of these elements.

Although Cu is an essential element for aquatic organisms, it can be toxic at high concentrations. Its adverse effects, particularly on aquatic plants, invertebrates, and fish, have been observed. Cu, can increase oxidative stress, leading to damage in biological systems (Brown et al., 1974). Mn, especially in waters with low hardness, can be toxic at high concentrations. The toxic effects of Mn can cause serious health issues in aquatic invertebrates and fish, particularly affecting organisms during the spawning period and in soft waters (Harford et al., 2015). Se is generally present in low concentrations in natural water systems and is an essential element for many organisms. However, high concentrations of Se can be toxic to aquatic life. Se can cause bioaccumulation in aquatic plants and animals and lead to reproductive disorders (Lemly, 1985). Therefore, controlling elements such as Se, Cu, and Mn in surface waters is crucial for the protection of aquatic ecosystems and the sustainability of aquatic life. Management strategies should be designed and implemented to mitigate these toxic effects.

The TP parameter is classified as Class III – Polluted Water at five of the sampling points. TP leaching from fertilizers used during agricultural activities can enter water bodies, leading to elevated TP levels. This issue is particularly observed in areas with intensive agriculture (Ascott et al., 2016). Additionally, insufficiently treated or untreated phosphorus from wastewater treatment facilities can contribute to increased phosphorus concentrations in water sources (Ruan and Gilkes, 2000). High levels of phosphorus lead to excessive nutrient loading in surface waters, resulting in eutrophication. This condition can cause a decrease in oxygen levels in aquatic ecosystems and lead to biological damage such as fish kills (Mayer et al., 2013). Moreover, it can negatively impact the recreational use of water resources and drinking water quality and promote the growth of toxin-producing cyanobacteria (blue-green algae) (Xie et al., 2014). Consequently, waters with high phosphorus concentrations can increase treatment costs and complicate sustainable water management (Kuo et al., 2009).

In addition, both TC and FC bacteria were detected at every sampling point. The contamination of water sources by human and animal waste can lead to high levels of FC and TC bacteria. Manure application and dairy runoff activities are thought to potentially increase both total and fecal coliforms in the environment. Moreover, rainwater, agricultural lands, parks, and other open areas can carry coliform bacteria into water sources through surface runoff. This process is particularly intense during rainy periods and can cause seasonal fluctuations in bacterial concentrations (Isobe et al., 2004). The presence of TC and FC bacteria poses significant risks to surface water sources. These bacteria are important indicators of waterborne diseases and can signal the presence of various pathogens, potentially leading to diarrheal disease, gastroenteritis, and other serious health issues in humans (Avigliano and Schenone, 2015). High levels of FC, in particular, can result in severe health problems, especially in recreational water sources and drinking water supplies. This can impair the chemical and aesthetic quality of water and threaten the health of aquatic ecosystems in the long term (Lalancette et al., 2014). Managing waters with high levels of TC and FC necessitates strengthening treatment and disinfection processes, as well as implementing stricter water quality monitoring protocols (Brion et al., 2000). High levels of coliform bacteria in water sources pose serious risks to both ecosystem and human health. Therefore, the protection of water sources and the control of pollution sources are of great importance for public health.

Evaluation of Correlation Matrices of Water Quality Parameters

The relationships among water quality parameters were also analyzed using a correlation matrix. The correlation matrix is a crucial method for exploring the relationships among water quality indicators. This method determines the strength and direction of linear relationships between different parameters, allowing researchers to understand how these parameters interact with each other. Specifically, high correlation coefficients indicate a strong linear relationship between two variables, revealing potential relational dynamics in water quality research. Another important aspect of the correlation matrix is its role in identifying sources of water pollution. Significant correlations can indicate common pollution sources, which facilitates the development of risk assessment and water quality management strategies. Additionally, the data obtained from this analysis method can be used in the design and development of water quality monitoring and management programs, enabling more effective and targeted approaches in environmental management. Such analyses optimize the use of time and resources in water quality research, enhancing scientific efficiency and accuracy.

Parameters such as DO, COD, BOD_5, FC, and TC are fundamental indicators used in assessing water quality. These criteria are utilized to analyze the chemical and biological quality of water. An examination of the correlation matrix of these water quality parameters reveals strong negative correlations between DO and COD, BOD_5 and COD, FC and COD, and TC and COD, with correlation coefficients of -0.74, -0.74, -0.89, and -0.82, respectively.

Additionally, it was found that there are very strong positive correlations between COD and BOD_5, COD and FC, COD and TC, BOD_5 and FC, BOD_5 and TC, and FC and TC, with correlation coefficients of 1, 0.96, 0.96, and 0.98, respectively (Figure 4).

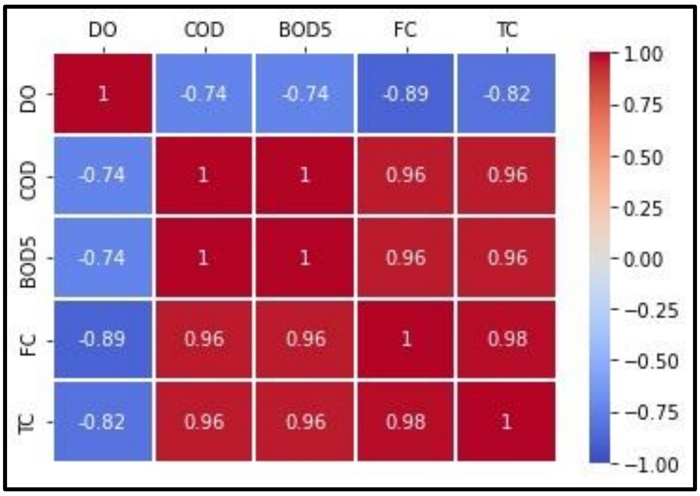

Figure 4. Correlation Matrix of Water Quality Parameters

Elements such as B, F, Fe, SO_4-S, and K play various critical roles in water quality assessments. These roles are important both in terms of the chemical composition of water and their effects on biological processes. Examination of the correlation matrix for these critical elements reveals very strong positive correlations between Fe and K, Fe and SO_4-S, and K and SO_4-S, with correlation coefficients of 0.95, 0.95, and 0.92, respectively (Figure 5). This indicates that these elements may originate from common sources or similar geochemical processes. These elements are often found in the same mineral structures and respond similarly to environmental factors. For example, atmospheric deposition can play a significant role in transporting these elements to water sources. Additionally, anthropogenic effects such as agricultural activities and industrial pollution can also increase the concentrations of these elements.

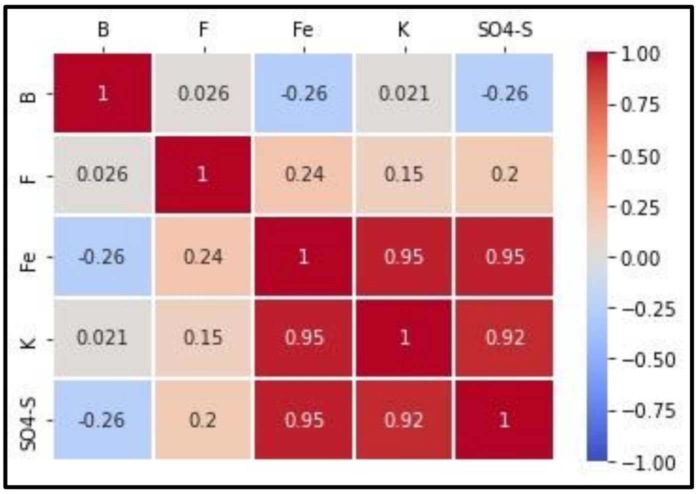

Figure 5. Correlation Matrix of Critical Water Quality Parameters

Elements such as Se, Mo, Zn, Cu, and Mn are essential trace elements required by living organisms in generally small amounts. These elements act as catalysts or coenzymes in many biological processes and are vital for health. Examination of the correlation matrix for these trace elements reveals moderate positive correlations between Se and Zn, and Mo and Zn, with correlation coefficients of 0.55 and 0.66, respectively (Figure 6).

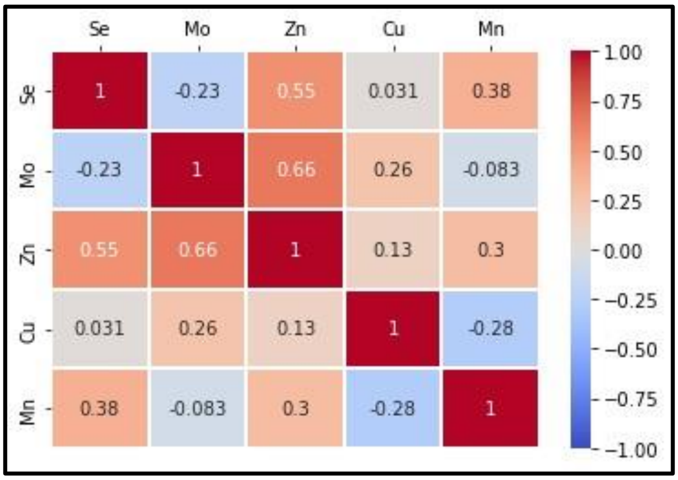

Figure 6. Correlation Matrix of Trace Water Quality Parameters

Parameters such as TKN, NH_4^+-N, TN, and TP are substances that primarily contribute to the nitrogen and phosphorus cycles in the context of water quality. They are important indicators related to nutrient loading in aquatic ecosystems. An examination of the correlation matrix for these nutrient pollution parameters reveals very strong positive correlations between TKN and NH_4^+, TKN and TN, and NH_4^+ and TN, with correlation coefficients of 0.97, 0.99, and 0.98, respectively. Additionally, strong positive correlations were found between TKN and TP, NH_4^+ and TP, and TN and TP, with correlation coefficients of 0.82, 0.78, and 0.87, respectively (Figure 7).

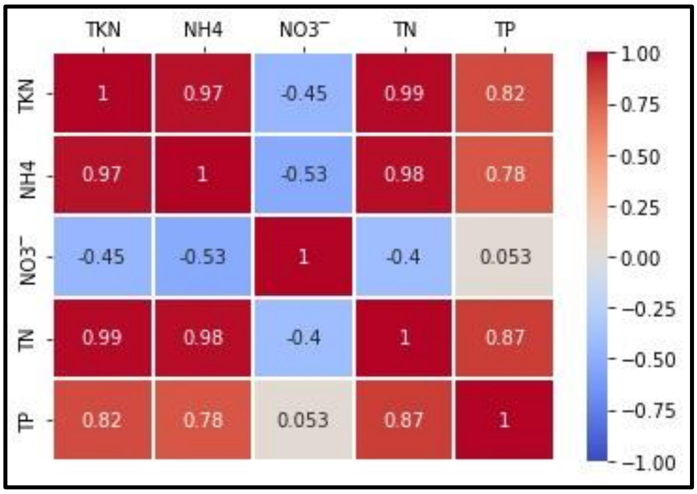

Figure 7. Correlation Matrix of Nutrient Pollution Parameters

CONCLUSION

The SMAB is a strategic region located in northwestern Turkey and encompasses a significant part of the Marmara Region. Rich in agriculture, industry, tourism, and water resources, this region is one of the critical areas that need to be protected and managed in line with Turkiye's sustainable development goals. Due to its strategic importance, the basin is exposed to numerous diffuse pollution sources. Examination of the data obtained from fieldwork reveals that high concentrations of TN and TP were detected at all six sampling points. Furthermore, the high correlation coefficients among pollutants increase the probability that pollution is reaching the receiving environment from non-point sources. These findings indicate that the TN and TP loads in the SMAB have a significant impact on water quality. Developing sustainable water management strategies is critical for controlling TN and TP loads. In this context, potential water management strategies are summarized below:

- Ensure fertilizers are applied at the correct time and in the appropriate amounts to prevent excessive use.
- Promote organic farming practices by reducing the use of chemical fertilizers and pesticides.
- Implement terracing, strip cropping, and conservation of vegetation to prevent soil erosion.
- Ensure proper collection, storage, and processing of animal wastes.
- Carefully manage the feed and nutrients used in animal husbandry.
- Establish and protect natural and artificial wetlands, aiming for these areas to naturally filter pollutants.
- Encourage the reduction of surface runoff through rainwater harvesting and green roof practices in urban areas.
- Organize training programs on sustainable agriculture and livestock practices.
- It is important to educate the public about water pollution and sustainable water use and to raise awareness.
- Ensure regular monitoring and reporting of water quality across the basin.
- Increase inspections and implement necessary legal regulations to ensure compliance with existing water quality standards.
- Establish buffer zones between agricultural areas and water sources and cover these zones with vegetation.
- Encourage the treatment of industrial and urban wastewater using advanced treatment methods.
- Facilitate the reuse of treated wastewater for agricultural irrigation or industrial processes.
- Water resources should be managed with a holistic approach, and integrated management plans should be developed with the involvement of all stakeholders.
- Update and effectively enforce legal regulations to protect water quality.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Declaration of Interests

The authors declare no conflict of interest. The paper is original unpublished work, and it is not under consideration for publication anywhere else. No data, text, or theories by others are presented, all relevant literature is cited.

Author contribution

Conceptualization, M.N.C. and H.K.Ö.; methodology, M.N.C. and H.K.Ö.; investigation, M.N.C. and H.K.Ö.; writing—original draft preparation, M.N.C. All authors have read and agreed to the published version of the manuscript.

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