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Research Article **Araştırma Makalesi**

Assessment of Büyük Menderes River (West of the Türkiye) Surface Water Quality with Water Quality Index (WQI), Comprehensive Pollution Index (CPI) and Geographic Information Systems (GIS)

Büyük Menderes Nehri (Türkiye'nin Batısı) Yüzey Suyu Kalitesinin Su Kalite Indeksi (WQI), Kapsamlı Kirlilik Indeksi (CPI) ve Coğrafi Bilgi Sistemleri (GIS) ile Değerlendirilmesi

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Abstract: In the present study some of the water quality parameters were spatially examined with water quality and pollution indices in the Büyük Menderes River (BMR). In addition, the more effective parameters on the indices were determined among the parameters measured in the study. The measured water quality parameters were detected as WT:16.5-25.9 oC, pH:7.5-9.3, DO:nd-12.2 mgL-1, EC:312-30215 µScm-1, Salt:0.17-19.6 ‰, NO2-N:nd-0.31 mgL-1, NO3-N:nd-1.08 mgL-1, NH4-N:0.035-25.2 mgL-1, TP:0.011-7.45 mgL-1, MBAS:nd-7.79 mgL-1 ve COD:nd-128.9 mgL-1. In the present study, several parameters were determined as the second class and third class of water quality according to the Turkish Water Pollution Control Regulation*. WQI value range was determined as from Bad (38.82) to Excellent (92.35), and CPI as from "Sub Clean (0.39) to Highly Polluted (9.62)" in the stream. It was determined that there was no compatibility between WQI and CPI used in determining the environmental risks in the study area. The GIS was found to be effective in interpreting the spatial distribution of the results obtained and in identifying the key areas that require control. Different statistical analyses were used to determine the relationships between variables. In multiple linear regression (MLR) analysis, it was determined that the most critical parameter affecting the indices was NH4-N. The results obtained from WQI and CPI in the present study indicate that anthropogenic activities are effective in the region.
*:TWPCR, Quality criteria of inland surface water resources in terms of general chemical and physicochemical parameters by Class

Keywords
- Surface water quality
- Water quality index
- Comprehensive pollution index
- Physicochemical parameters

Özet: Bu çalışma, Büyük Menderes nehrindeki bazı su kalite parametrelerini mekansal olarak su kalite ve kirlilik indeksleri ile incelemeyi, ayrıca çalışmada ölçülen hangi parametrenin indeksler üzerinde daha etkili olduğunu belirlemeyi amaçlamıştır. Ölçülen su kalite parametreleri Yüzey Suyu Sıcaklığı:16,5-25,9 ^{o}C, pH:7,5-9,3, Çözünmüş Oksijen:nd-12,2 mgL^{-1}, Elektriksel İletkenlik:312-30215 µScm^{-1}, Tuzluluk:0,17-19,6‰, Nitrit Azotu (NO_2-N):nd-0,31 mgL^{-1}, Nitrat Azotu (NO_3-N):nd-1,08 mgL^{-1}, Amonyum Azotu (NH_4-N):0,035-25,2 mgL^{-1}, Toplam Fosfor:0,011-7,45 mgL^{-1}, Anyonik Yüzey Aktif Madde:nd-7,79 mgL^{-1} ve Kimyasal Oksijen İhtiyacı:nd-128,9 mgL^{-1} olarak tespit edildi. Çalışmamızda Türkiye Su Kirliliği Kontrolü Yönetmeliği (SKKY, Kıtaiçi yerüstü su kaynaklarının genel kimyasal ve fizikokimyasal parametreler açısından sınıflarına göre kalite kriterleri)'ne göre birden fazla parametrenin ikinci sınıf ve üçüncü sınıf su kalitesinde olduğu belirlendi. Su kalitesi indeksi değer aralığı akarsuda Kötü (38,82)-Mükemmel (92,35), kapsamlı kirlilik

Anahtar kelimeler
- Yüzey suyu kalitesi
- Su kalite indeksi
- Kapsamlı kirlilik indeksi
- Fizikokimyasal parametreler

indeksi ise "Az Kirli (0,39)-Çok Kirli (9,62)" şekinde tespit edildi. Çalışma alanında çevresel risklerin belirlenmesinde kullanılan su kalite indeksi ve kapsamlı kirlilik indeksi arasında bir uyumun olmadığı belirlendi. Coğrafi bilgi sisteminin, elde edilen sonuçların mekansal dağılımının yorumlanmasında ve kontrol gerektiren kilit alanların belirlenmesinde etkili olduğu görüldü. Değişkenler arası ilişkilerin belirlenmesinde farklı istatistiksel analizler kullanıldı. Çoklu doğrusal regresyon (MLR) analizinde indeksleri etkileyen en önemli parametrenin NH_4-N olduğu tespit edildi. Çalışma sonucunda elde edilen su kalite indeksi ve kapsamlı kirlilik indeksi sonuçları antropojenik faaliyetlerin bölge üzerinde etkili olduğuna işaret etmektedir.

1. INTRODUCTION

Water is necessary for the continuity of vital activities in every period of human life, and the presence and quality of water are especially important (Minareci and Çakir, 2018; Şimşek and Mutlu, 2023). Sustainable use of surface water is one of the indispensable issues, especially considering freshwater resources. Determining the quality and pollution level of these waters is essential for the environment and human health (Döndü et al., 2022). River water quality can vary depending on numerous factors such as the geology of the area, vegetation and human activities (point and non-point). River water pollutants usually come via stream discharges, groundwater seepage, stormwater runoff, and atmospheric deposition (Yang et al., 2021). Surface water quality in rivers is indispensable for both human communities and aquatic organisms (Zhong et al., 2018). However, it has been reported by many researchers that water quality deteriorates due to anthropogenic activities and this situation is a serious threat especially for developing countries (Singh et al., 2005; Gazzaz et al., 2012; Yılmaz and Koç, 2016; Aksever and Büyükşahin, 2017; Wu et al., 2018; Yang et al., 2020; Yang et al., 2021; Döndü et al., 2022; Elassassi et al., 2022; Özdemir et al., 2022). Besides, river ecosystems attract more attention due to their importance in ecological integrity as well as for their economic contribution (Sun et al., 2019; Tibebe et al., 2019).

In recent years, with the increasing importance of water quality, different evaluation methods have been developed and used. The most common methods in scientific studies today include the use of water quality and pollution indices (Hurley et al., 2012; Şener et al., 2017; Ewaid et al., 2018; Matta et al., 2020; Yılmaz et al., 2020; Valentini et al., 2021; Döndü et al., 2022; Şimşek et al., 2022; Özdemir et al., 2023; Şimşek and Mutlu, 2023), principal component analysis (PCA) (Olsen et al., 2012; Wang et al., 2017; Zeinalzadeh and Rezaei, 2017; Basatnia et al., 2018; Zhong et al., 2018; Elassassi et al., 2022), geographic information system (GIS) (Şener et al., 2017; Döndü et al., 2022), and multiple linear regression (MLR) (Basatnia et al., 2018; Ewaid et al., 2018; Valentini et al., 2021). One of the most used interpolation methods on GIS is Inverse Distance Weighted (IDW) (Aminu et al., 2015; Rostami et al., 2019). IDW is one of the most used g geostatistical and mathematical interpolation techniques nowadays (Yang et al., 2020). This technique is used for spatiotemporal mapping and surveying of surface water quality, assessing potential pollution of river water (Zhong et al., 2018).

Environmental studies were carried out at different locations in the BMR, including many areas of the basin (Akcay et al., 2003; Koca et al., 2008; Bulut et al., 2012; Tekin Özan and Aktan, 2012; Yilgor et al., 2012; Gülcü-Gür and Tekin-Özan, 2015; Yılmaz and Koç, 2016; Aksever and Büyükşahin, 2017; Durmaz et al., 2017; Minareci and Çakir, 2018; Minareci et al., 2018; Algül and Beyhan, 2020; Esen and Hein, 2020; Yılmaz et al., 2020; Akyildiz and Duran, 2021). However, among these studies, there is almost no detailed study in which water quality and pollution indices are used alone or together with GIS and covering the entire basin. In this regard, it is thought that our study is especially important considering the quality of drinking and irrigation water used extensively in the region.

The aims of this study are (i) to evaluate the current status of water with water quality and pollution indices in BMR which is one of the most important rivers of Türkiye, and to compare the indices (ii) to determine the most effective water quality parameters on quality and pollution indices (iii) to analyze the water quality parameters spatially and to evaluate them with statistical analyses and GIS.

2. MATERIAL and METHODS

2.1. Study area and sampling sites

The BMR has a length of 584 km and it is the longest river in the Aegean region of Türkiye (Figure

1). BMR is located in Western Anatolia, southwest of Türkiye, between the coordinates 37°04'-38°95' North and 27°05'-30°76' East. The borders of the basin, which constitutes 3.2 percent (26.361 km^2) of Türkiye's land surface, includes many provinces such as Aydın, Uşak, Denizli, Muğla, Afyon, Isparta, Burdur and İzmir (Durkan et al., 2008; Koca et al., 2008; Yılmaz and Koç, 2016; Durmaz et al., 2017; Minareci et al., 2018; SYGM, 2018; Yılmaz et al., 2020).

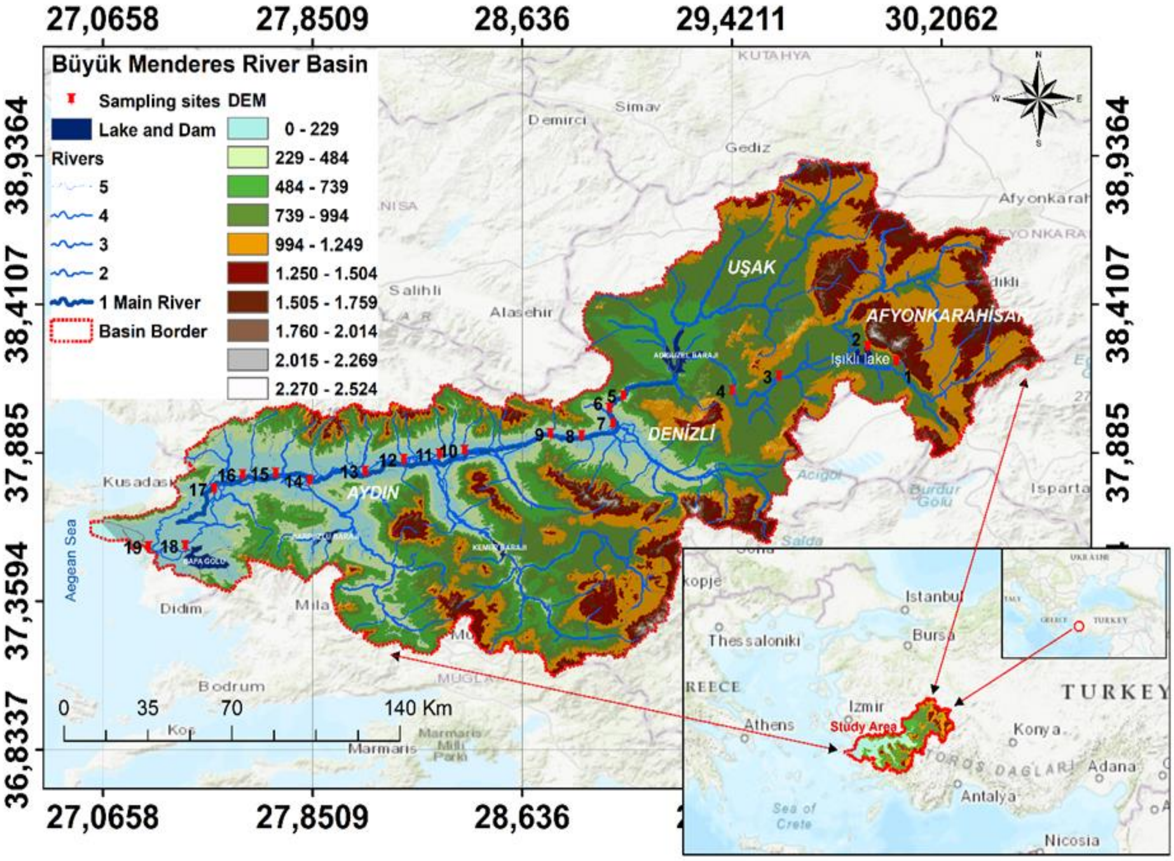

Figure 1. Study area map, sampling sites and digital elevation model (DEM).

Most of the river water is used for irrigation purposes. The population of the basin has reached 2.5 million people, the majority of whom are distributed in 323 municipalities (Yılmaz et al., 2020). The river basin is very important from an agricultural point of view (Minareci ve Çakir, 2018). Cotton, wheat, corn, clover, sunflower, vegetables and fruits are the traditional cultivated of these areas according to the irrigation tradition (SYGM, 2018). Leather and textile industry are highly developed in the basin (Çondur and Cömertler, 2010). The region is adversely affected by domestic waste water originating from settlements, industrial waste water originating from industrial establishments, water returning from irrigation containing fertilizers and chemicals (because pesticides are used) and geothermal power plant waste water (Akcay et al., 2003; Durkan et al., 2008; Koca et al., 2008; Yılmaz and Koç, 2016; Minareci and Çakir, 2018). In the BMR, chosen as the research area, 19 sampling sites with potential pollution were determined and samples were collected from points shown below (Table 1). The view of the basin boundary, study area height (DEM) and sampling sites are given in Figure 1.

Table 1. Coordinates and names of sampling sites.

1 Gökgöl, Denizli (38°12'19.02"N-30°2'19.37"E)	**11** Nazilli, Aydın (37°52'32.55"N-28°19'40.40"E)
2 Işıklı Lake, Denizli (38°15'25.97"N 29°55'41.85"E)	**12** Yenipazar, Aydın (37°51'27.72"N-28°11'33.57"E)
3 Yahyalı, Denizli (38° 09'6.50"N-29°35'53.05"E)	**13** Köşk, Aydın (37°48'58.69"N-28°2'53.79"E)
4 Çal, Denizli (38° 6'1.84"N-29°25'21.55"E)	**14** Aydın (37°46'56.36"N-27°50'22.55"E)
5 Cindere, Denizli (38° 5'0.63"N-29°0'53.45"E)	**15** Yazıdere, Aydın (37°48'35.31"N-27°42'46.76"E)
6 Mahmutlu, Denizli (38° 2'17.92"N-28°57'46.44"E)	**16** Karaağaçlı, Aydın (37°48'13.88"N-27°35'19.17"E)
7 Ahmetli, Denizli (37°59'7.80"N-28°58'30.50"E)	**17** Söke, Aydın (37°45'11.41"N-27°28'54.47"E)
8 Karakıran, Denizli (37°56'31.76"N-28°51'29.88"E)	**18** Sarıkemer, Aydın (37°33'7.75"N-27°22'25.61"E)
9 Buharkent, Aydın (37°56'50.34"N-28°44'35.71"E)	**19** Batıköy, Aydın (37°32'52.29"N-27°14'14.01"E)
10 Hamzalı, Aydın (37°53'21.65"N-28°25'14.24"E)	

2.2. Water quality parameters and experimental studies

Samples were collected by conducting a field study in September 2021 from the sampling sites determined in the BMR. Water samples were filled into the 2 L polyethylene bottles and transported as a cold chain to the laboratory. Electrical conductivity (EC, μScm^{-1}), salinity (Salt, %o), pH, water temperature (WT, ^oC), and dissolved oxygen (DO, mgL^{-1}) were measured at the sampling sites using a multiparameter device named the Hach HQ40d brand. All the parameters measured in this study and the methods used are given in Table 2. Water analysis was done by APHA (2017) and EPA (1971) methods in the laboratory of Mugla Sıtkı Koçman University Environmental Problems Research and Application Centre, accredited by the internationally recognized Turkish Accreditation Agency (TURKAK). TIN (NH_4-N+NO_2-N+NO_3-N) was obtained by summing the nitrogen values. The samples were studied in 3 repetitions and the averages were noted. In the calibration charts prepared for the parameters, r^2>0.99 was determined. Double distilled water obtained from the Human Zeneer UP900 brand distilled water device was used in the preparation of all solutions. In analyses using the colorimetric method, measurements were made using an Agilent Cary60 UV/V brand spectrophotometer. All chemicals used in the analyses are of analytical purity and belong to Merck and Sigma Aldrich brands.

Table 2. Methods used in water analysis.

Analyses	Name of the method	Reference Metod	Measurement range
WT	Laboratory and field methods	SM 2550 B	0-100 ^oC
pH	Electrometric method	SM 4500 H^+B	1-14
DO	Membrane electrode method	SM 4500-O H	0-50 mgL^{-1}
EC	Laboratory and field methods	SM 2510 B	0-200 mS/cm
Salt	Laboratory and field methods	SM 2520 B	0-70 ‰
NO_2^--N	Spectrophotometric	SM 4500 B	>0.01
NO_3^--N	Brucine method	EPA 352.1	>0.1
NH_4^+-N	Spectrophotometric	SM 4500 B	>0.02
TP	Spectrophotometric	SM 4500-P B ve E	>0.01
MBAS	Spectrophotometric	SM 5540-C	>0.025
COD	Titrimetric method	TS2789 (Part A- B)	>1

SM: Standard method, TS: Turkish Standard

2.3. Water quality index (WQI) and Comprehensive pollution index (CPI)

WQI is a single number that is easy to understand and interpret mathematically and that is derived from the conversion of multiple water quality data (Kükrer and Mutlu, 2019). The following equation (1) was used to determine the WQI.

$$WQI = \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i} \quad 1$$

In this equation, n is the total number of parameters, C_i is the value assigned to parameter i after normalization and P_i is the relative weight of parameter i (Pesce and Wunderlin, 2000). P_i values range between 1 and 4 (Kocer and Sevgili, 2014). The WQI is calculated bewteen 0 and 100 and a value closer to 100 indicates better water quality conditions. Water quality is divided into five classes according to WQI values: very bad (0-25), bad (26-50), medium (51-70), good (71-90) and excellent (91-100) (Kocer and Sevgili, 2014). Limit values of Turkish water quality standards were taken into consideration during the calculations made (TS266, 2005). In this study, eight water quality parameters (WT, pH, DO, NO_2-N, NO_3-N, NH_4-N, TP and COD) were used for WQI calculation.

CPI is used to determine the pollution level at a given point using water quality monitoring data (Son et al., 2020). The following empirical equation (2) was used to determine the CPI.

$$CPI = \frac{1}{n}\sum_{i=1}^{n} Pli \quad (2)$$

where n is the number of parameters; PI_i is the pollution index number i. PI_i is calculated according to the following equation (3).

$$PI_i = \frac{Ci}{Si} \quad (3)$$

where C_i is the concentration of parameter in water; Si is the limit value according to environmental standards. CPI is classified into five categories: Clean (0-0.2), Sub clean (0.21-0.40), slightly polluted (0.41-1.00), medium polluted (1.01-2.00), and heavily polluted (CPI≥2.01). In this study, eight water quality parameters (WT, pH, DO, NO2-N, NO3-N, NH4-N, TP, and COD) were used for CPI calculation.

2.4. Data analysis

In this study, descriptive statistics and Kolmogorov-Smirnov & Shapiro-Wilk normality tests were used to determine the distribution of the data, Kruskal-Wallis test was used to determine the differences of the variables between sampling sites, Spearman's rho correlation was used to analyze the relationships between the variables, PCA was used to detect potential pollutant sources and the relationships between the data and MLR was used to determine the parameters affecting the water quality indices. SPSS 22 and Origin 2022b were used for statistical analyses. Before performing MLR analysis, analysis prerequisites (linearity, normality, multicollinearity, and homoscedasticity) were fulfilled. For multicollinearity control, correlation coefficients between all independent variables were found to be less than 0.8, and the variance inflation factor (VIF) of linear regression was found to be <10 (Ewaid et al., 2018). The spatial analysis of the collected data was conducted in GIS, and a thematic map of each water variable was developed by using the IDW interpolation technique (Gong et al., 2014). During the mapping process, ArcGIS software (10.7.1) was utilized.

3. RESULTS and DISCUSSION

3.1. Water quality and statistical analysis

The descriptive statistical results of the data in the study area are given in Table 3, the distribution of the data at the sampling sites is given in Figure 2 and the correlation results are given in Figure 3. The differences in the variables between sampling sites are given in Table 5. A significant difference was found between the distributions of the variables at the sampling sites (Table 5, p=0.000). The distributions of the values in GIS are given in Figure 4, Figure 5, and Figure 6.

Table 3. Physicochemical analysis results in water samples.

Descriptive Statistics					
	Unit	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
WT	^oC	16.5	25.9	21.5	2.42
pH	-	7.5	9.3	8.3	0.49
DO	mgL^{-1}	nd	12.2	6.84	3.70
EC	μScm^{-1}	312.0	30215	3101	6614
Salt	%o	0.17	19.6	1.86	4.29
NO_2-N	mgL^{-1}	nd	0.310	0.060	0.08
NO_3-N	mgL^{-1}	nd	1.08	0.28	0.31
NH_4-N	mgL^{-1}	0.035	25.2	2.75	6.28
TP	mgL^{-1}	0.011	7.45	0.85	2.22
MBAS	mgL^{-1}	nd	7.79	0.54	1.74
COD	mgL^{-1}	nd	128.9	41.5	34.1

nd: not determined

WT is one of the most important parameters affecting aquatic life. Living things are very sensitive to water temperature changes (Özdemir et al., 2014). Physical properties of water such as density, viscosity, vapor pressure, surface tension and chemical properties such as biochemical reaction rates are significantly affected by water temperature (Wu and Kuo, 2012). The highest WT was detected at sampling site fourteen with 25.9 ^{o}C, while the lowest value was detected at sampling site one with 16.5 ^{o}C (Figure 1, Figure 2a and Table 3).

Table 4. The comparison of this study with other studies and standards.

References/ Parameters	WT	pH	DO	MBAS	COD	TP	NH_4-N	NO_2-N	NO_3-N	WQI	CPI
Akyildiz and Duran, (2021)	19.74	8.29	7.51	-	-	-	-	0.52	3.31	-	-
Yılmaz et al. (2020)	-	8.03	7.30	-	16.64	-	0.45	0.17	2.07	a-b	-
Minareci et al. (2018)	15.6	8.24	6.04	0.24	-	0.018	-	-	-	-	-
Aksever and Büyükşahin, (2017)	10.53	8.15	-	-	-	-	-	-	-	-	-
Yılmaz and Koc, (2016)	-	-	7.43	-	29.60	-	-	0.06	2.02	-	-
Bulut et al. (2012)	14.30	8.17	9.08	-	-	-	-	-	1.05	-	-
Kara et al. (2004)	11.0	7.5	7.33	-	20.0	-	-	0.001	0.34	-	-
Akcay et al. (2003)	19.0	8.15	11.65	-	42.4	-	-	-	-	-	-
This study (2022)	21.5	8.3	6.84	0.54	41.5	0.85	2.75	0.06	0.28	c-d	e-f
TWPCR (2023) 1st	≤25	6-9	>8	-	<25	<0.08	<0.2	-	<3	-	-
TWPCR (2023) 2nd	≤25	6-9	6	-	50	0.2	1	-	10	-	-
TWPCR (2023) 3rd	≤30	6-9	<6	-	>50	>0.2	>1	-	>10	-	-

a: good, b: very poor, c: bad, d: excellent, e: Sub clean, f: heavily polluted

Gökgöl Wetland Protection Area is in the sampling region one and is located between Afyon-Denizli border. Sampling site fourteen is at the entrance to the center of Aydın, and high concentrations of MBAS were detected in this region. Mean WT was determined as 21.5±2.42 ^{o}C in the BMR basin. WT showed a positive ($p<0.001$) correlation with pH and MBAS, and a negative ($p<0.001$) correlation with NO_3-N (Figure 3). The average water temperature value we obtained is higher than the studies conducted in the region and is of the first class water quality determined by TWPCR (2023) (Table 4).

pH significantly affects the treatment and use of water, and the pH of water is a measure of its reactive properties (Bulut et al., 2012; Aksever and Büyükşahin, 2017). The pH of the water consumed by humans is between 6.5 and 8.5, and pH is very important as it affects the solubility, availability and use of nutrients by aquatic organisms (Yılmaz et al., 2020; Ram et al., 2021).

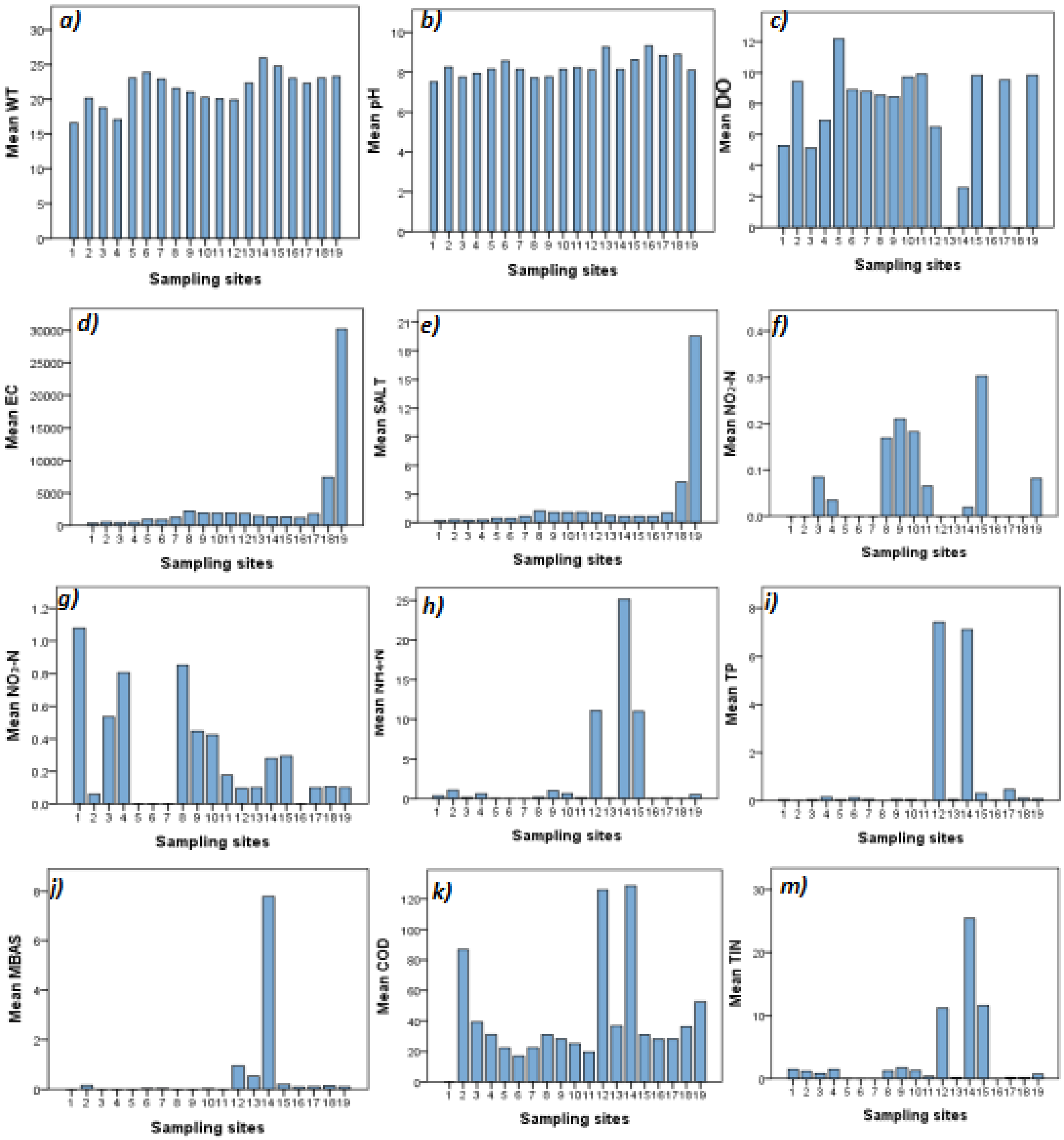

Figure 2. Distribution of data in the study area at sampling sites (a:WT, b:pH, c:DO, d:EC, e:Salt, f:NO_2-N, g:NO_3-N, h:NH_4-N, i:TP, j:MBAS, k:COD, m:TIN).

The highest pH was determined as 9.3 at sampling site sixteen, while the lowest value was determined at sampling site one as 7.5 (Figure 1, Figure 2b and Table 3). At sampling site sixteen of Karaağaçlı (Aydın) region, the water became very shallow and the flow almost came to a standstill (Figure 1). While pH showed a high positive correlation (r=0.54) with MBAS, it showed a high negative correlation (r=-0.65) with NO_3-N (Figure 3). The average pH value we determined in the basin is higher than other studies conducted in the region, and it is of the first class water quality determined by TWPCR (2023) (Table 4).

DO is one of the most important water quality parameters (Yılmaz et al., 2020; Döndü et al., 2022; Özdemir et al., 2022). DO below 2 mg/l is called hypoxis and is not suitable for the survival of living organisms (Rounds et al., 2013).

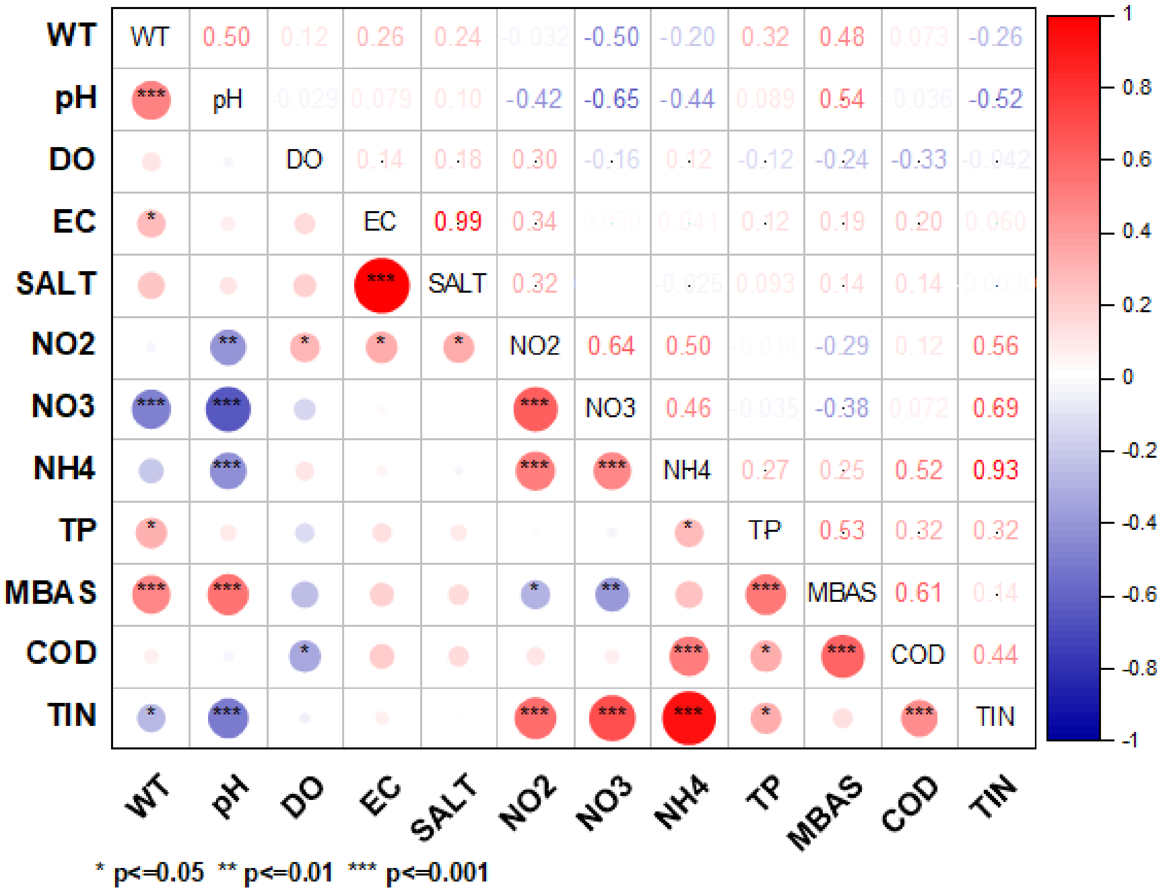

Figure 3. Correlation results of water quality parameters.

The highest DO was determined as 12.20 mgL^{-1} at sampling site five, while the lowest value was determined with nd (not determined) at sampling sites thirteen, sixteen, and eighteen (Figure 1, Figure 2c, and Table 3). The mean DO was determined as 6.84±3.7 mgL^{-1} in the basin. Sampling site thirteen located in the Köşk (Aydın) region and sampling site eighteen located in the Sarıkemer (Aydın) region were quite shallow and the amount of water was greatly reduced. Agricultural areas are dense in these areas and there are olive oil factories at some points. However, it is affected by multiple streams and environmental activities. The average DO value we determined in the basin is one of the lowest values in the studies conducted in the region, and it is in the second-class water quality determined by TWPCR (2023) (Table 4).

Table 5. Kruskal Wallis Test results for water quality parameters.

Test Statistics[a,b]											
	WT	pH	DO	EC	Salt	NO_2-N	NO_3-N	NH_4-N	TP	MBAS	COD
Chi-Square	55.294	55.665	55.851	55.884	55.702	55.899	55.224	55.657	55.809	55.832	55.638
Asymp. Sig.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

a. Kruskal Wallis Test
b. Grouping Variable: Sampling Sites

EC is a parameter that indicates the ability to conduct current in the water and the total amount of salt or ions dissolved in the water (Yılmaz et al., 2020). The salinity of water used for drinking is specified as 1500 µScm^{-1} (Tibebe et al., 2019). Yilmaz et al. (2020) determined the EC value as 1160 μScm^{-1}, and Akyildiz and Duran (2021) as 1449 μScm^{-1}. In our study, the highest EC was determined with 30215 μScm^{-1} at sampling site nineteen, while the lowest value was determined at sampling site one with 312 μScm^{-1} (Figure 2d). It showed a high positive correlation ($p<0.001$) with EC-Salt (Figure 3). Sampling site nineteen is located in the outlet region of the basin (Batiköy, Aydın) close to the marine area (Figure 1). Akyildiz and Duran (2021) determined the salinity value as 2.61% in their studies in the basin. The salinity data in our research move in parallel with the EC values. The highest salinity was determined at sampling site nineteen as 19.56%, while the lowest value was determined at sampling site one as 0.17% (Figure 1).

NO_2-N does not accumulate much in the environment and turns into nitrate nitrogen as a by-product (Boyd and Tucker, 1992). The highest NO_2-N was detected at sampling site fifteen with 0.310 mgL^{-1}, while the lowest value was detected as nd at more than one sampling site (Figure 1, Figure 2f, and Table 3). Sampling site fifteen is located in Yazıdere (Aydın) region and there are dense agricultural areas and domestic discharges around it. Again in this region, there are retreats and shallows in the water. The mean NO_2-N value was determined as 0.06 mgL^{-1}. NO_2-N showed a high positive correlation with NO_3-N and NH_4-N (Figure 3). The average NO_2-N value we obtained in the study was determined at a low level compared to Akyildiz and Duran (2021) and Yılmaz et al. (2020) (Table 4).

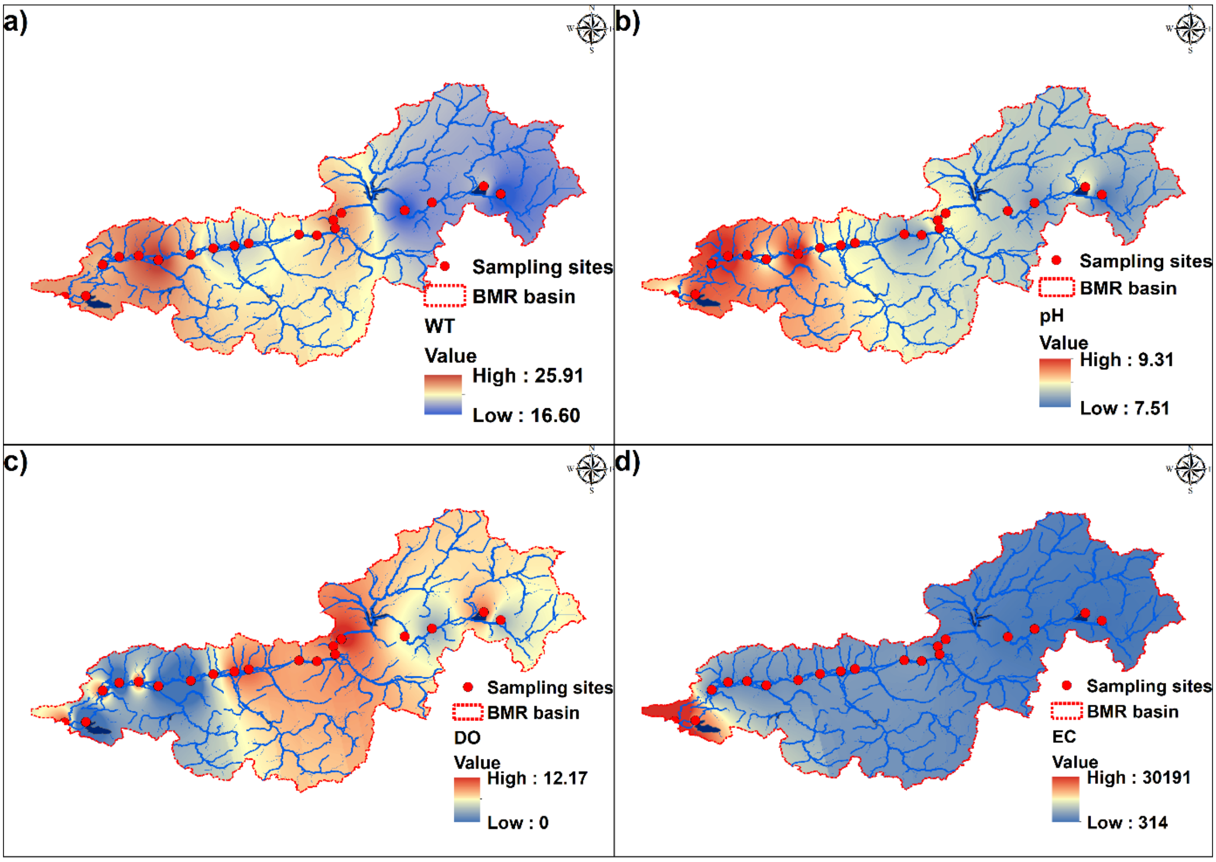

Figure 4. GIS map of mean WT (a), pH (b), DO (c), and EC (d).

NO_3-N values above 5 mg/l in surface water indicate intense domestic and agricultural activities (Chapman and Kimstach, 1996). While the highest NO_3-N value was detected at sampling site one as 1.081 mgL^{-1}, the lowest value was found in more than one sampling sites as nd (Figure 1, Figure 2 and Table 3). The presence of animal fertilizers and intensive agricultural work at sampling site one may be effective in increasing these values. Especially the pouring of animal manures to the bottom of the trees near the river can contribute to this situation. The mean value was found to be 0.28 mgL^{-1}. The average nitrate nitrogen value we determined in the basin is one of the lowest values among the studies conducted in the region, and it is of the first class water quality determined by TWPCR (2023) (Table 4).

NH_4-N is the most general form of nitrogen in aquatic ecosystems. Ammonia can pass quickly through the gills, causing nervous system toxicity and even death (Osman and Kloas, 2010; Yılmaz and Koc, 2016). The highest NH_4-N value was determined at sampling site fourteen as 25.2 mgL^{-1}, while the lowest value was determined at sampling site eighteen as 0.035 mgL^{-1} (Figure 1, Figure 2h and Table 3). At this point, it is thought that it is effective in increasing the NH_4-N values of both agricultural and industrial wastewater. The average NH_4-N value we determined in the basin is higher than the studies conducted in the region, and it is in the third class water quality determined by TWPCR (2023) (Table 4).

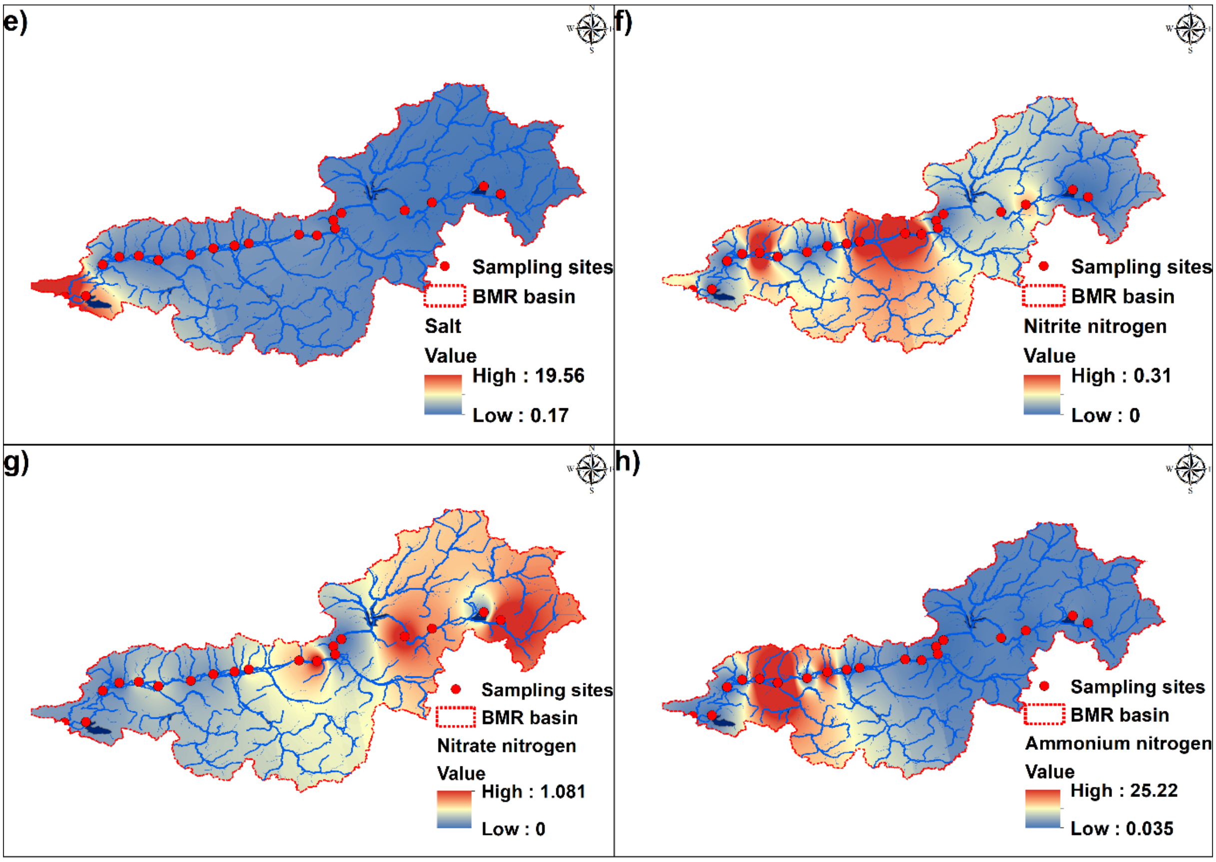

Figure 5. GIS map of mean Salt (e), NO_2-N (f), NO_3-N (g), and NH_4-N (h).

Phosphate concentrations ranging from 0.05 to 0.1 mgL^{-1} are considered threshold values for natural waters (Tibebe et al., 2019). The highest TP was detected at sampling site twelve as 7.45 mgL^{-1}, while the lowest value was determined at sampling site two and eight as 0.011 mgL^{-1} (Figure 1, Figure 2i and Table 3). Sampling site twelve, which is close to Yenipazar (Aydın) district, is quite shallow and the water contained is dark in color. The average TP value we determined in the basin is higher than the studies conducted in the region, and it is in the third class water quality determined by TWPCR (2023) (Table 4).

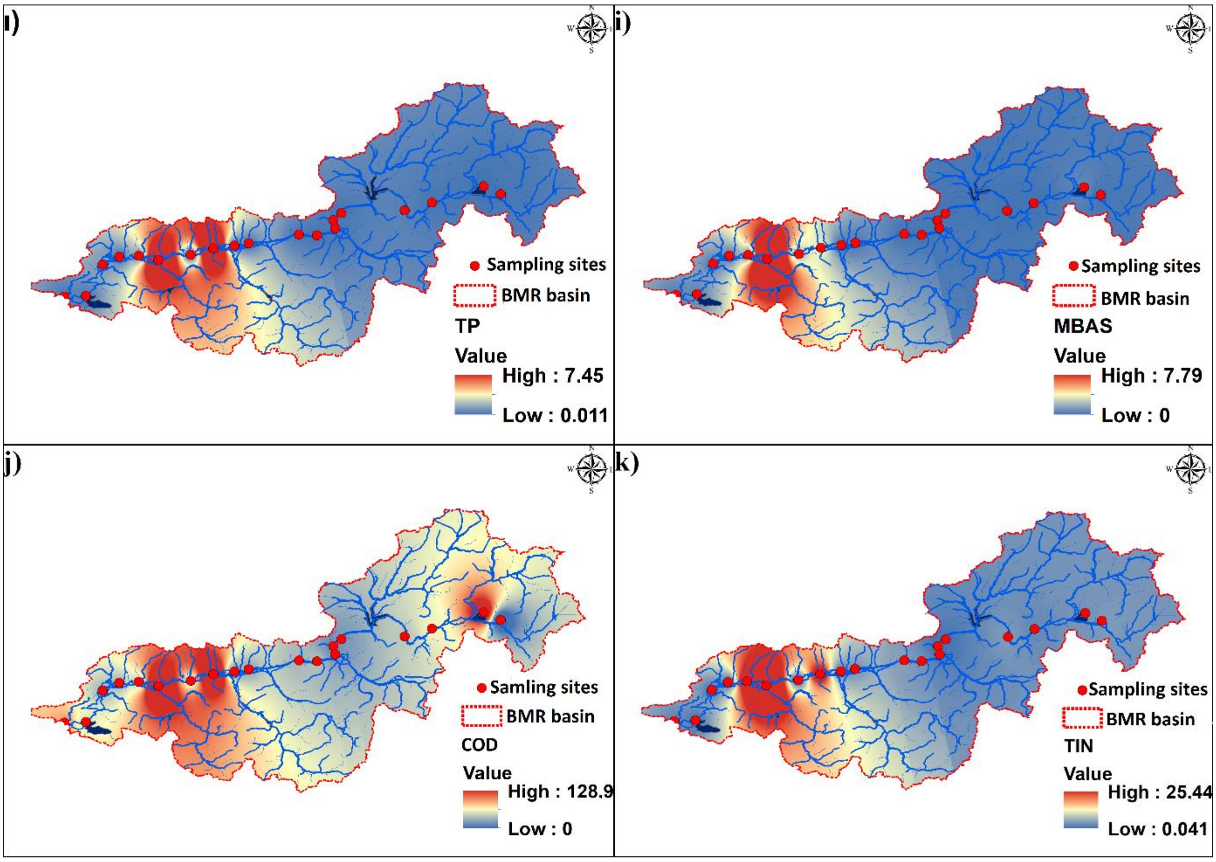

Figure 6. GIS map of mean TP (ı), MBAS (i), COD (j) and TIN (k).

With bioaccumulation, MBAS can pose a threat to human health. Since MBAS is not naturally found in waters, it may be caused by activities along the basin and cause eutrophication in water bodies (Wu and Kuo, 2012). The highest MBAS was detected at sampling site fourteen as 7.79 mgL^{-1}, while the lowest value was determined at more than one sampling sites as nd (Figure 1, Figure 2j and Table 3). The white foamy appearance and detergent smell at the sampling site 14, which is close to the central region of Aydın, is in line with the high data we obtained. The average MBAS value we determined in the basin is higher than Minareci et al. (2018) (Table 4).

COD is accepted as a useful measure of water quality as it indicates the amount of organic pollutants (Viessman and Hammer, 1998). High COD values are indicative of the pollution of wastewater discharged from residential, agricultural and industrial activities (Bellos et al., 2004; Yılmaz and Koc, 2016). The highest COD was detected as 128.9 mgL^{-1} at sampling site fourteen, while the lowest value was determined as nd at sampling site one (Figure 1, Figure 2k and Table 3). We found that the average COD value in the basin was higher than previous studies, and is of the second class water quality determined by TWPCR (2023) (Table 4).

Total inorganic nitrogen (TIN) concentration was obtained by calculating nitrogen values. The highest TIN was determined at sampling site fourteen as 25.44 mgL^{-1}, while the lowest value was determined at sampling site six as 0.041 mgL^{-1} (Figure 1, Figure 2m and Table 3).

PCA analysis was applied to determine the similarity relationships between water quality variables and the sources of pollutants (Figure 7). Kaiser-Meyer-Olkin (KMO)–Bartlett test and Varimax (Rotation Method) Kaiser normalization were used to determine whether the data set was suitable for PCA. KMO (>0.53) - Bartlett's test was p=0.000, indicating that PCA can be used in the field. Three main components with eigenvalues greater than 1 (3 components extracted) and constituting 73.8% of the total variance were identified for the study area. Factors are classified according to their effect sizes as "strong" (>0.75), "moderate" (0.75-0.50) and "weak" (0.50-0.30) (Li et al., 2011). In PC 1 (with 33.87% of the total variance), NH_4-N, MBAS, COD and TP have strong load, while WT has weak positive load. In PC 2 (with 21.85% of the total variance), NO_3-N has strong positive loads, while NO_2-N and DO have moderate positive load, WT has strong negative load, and pH has moderate negative load. PC 1 and PC 2 refer to the impact of anthropogenic studies such as agricultural activities, agricultural fertilizers, leather and textile industry, olive oil factories, domestic and industrial wastes. PC 3 showed strong positive load for EC and Salt as 18.09%, WT and DO showed weak positive load. PC 3 points to climatic and biochemical processes.

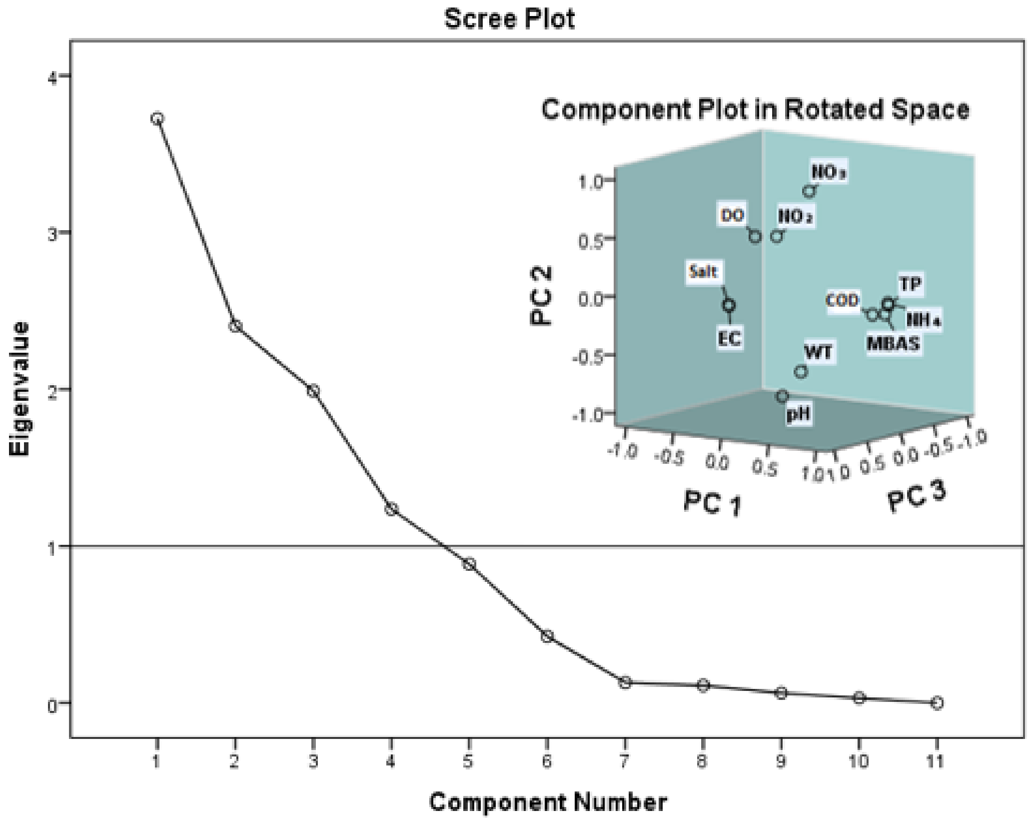

Figure 7. PCA analysis of water variables.

3.2. Water quality index (WQI) and Comprehensive pollution index (CPI) results

The smallest WQI value obtained in the study was 38.82 at sampling site fourteen, and the highest WQI was determined at sampling site six as 92.35 (Figure 8 and Table 6). However, the lowest CPI value was 0.39 at sampling site sixteen and the highest CPI was detected at sampling site fourteen as 9.62 (Figure 8 and Table 6). The distribution of the obtained WQI and CPI values in GIS is given in Figure 9. The most important result seen in Figure 8, Figure 9, Table 6 is that the results of both indices were not found to be compatible. Therefore, the use of a single index may not be sufficient to determine the quality or pollution of water and may not give accurate results. However, when the basin is evaluated regionally, both indices point to 3 main regions in total. The first of these is located between sampling sites one and seven located in the a rural area and partially agricultural. Human activities are not very intense at these points. The second region is located between sampling sites eight and fifteen. This area is directly and indirectly affected by the population density of Aydın and Denizli provinces. There are more than one environmental activity (mainly domestic, industrial and agricultural) in the second region. The third region is between the sampling sites sixteen and nineteen. In this region, which is close to the marine area, mostly the effect of domestic wastes and agricultural activities is seen (Figure 1 and Figure 9). However, the existence of many small streams affecting the basin and pouring into the sea with the main river should not be ignored. It is thought that natural or wastewater coming from these areas will be effective in the instant and point changes of the data. In addition, water quality parameters in areas close to the sea may be diluted with sea water. Considering all these factors, it is seen in the GIS map as well as the data that the CPI gives more understandable and certain results together with the results obtained (Figure 9).

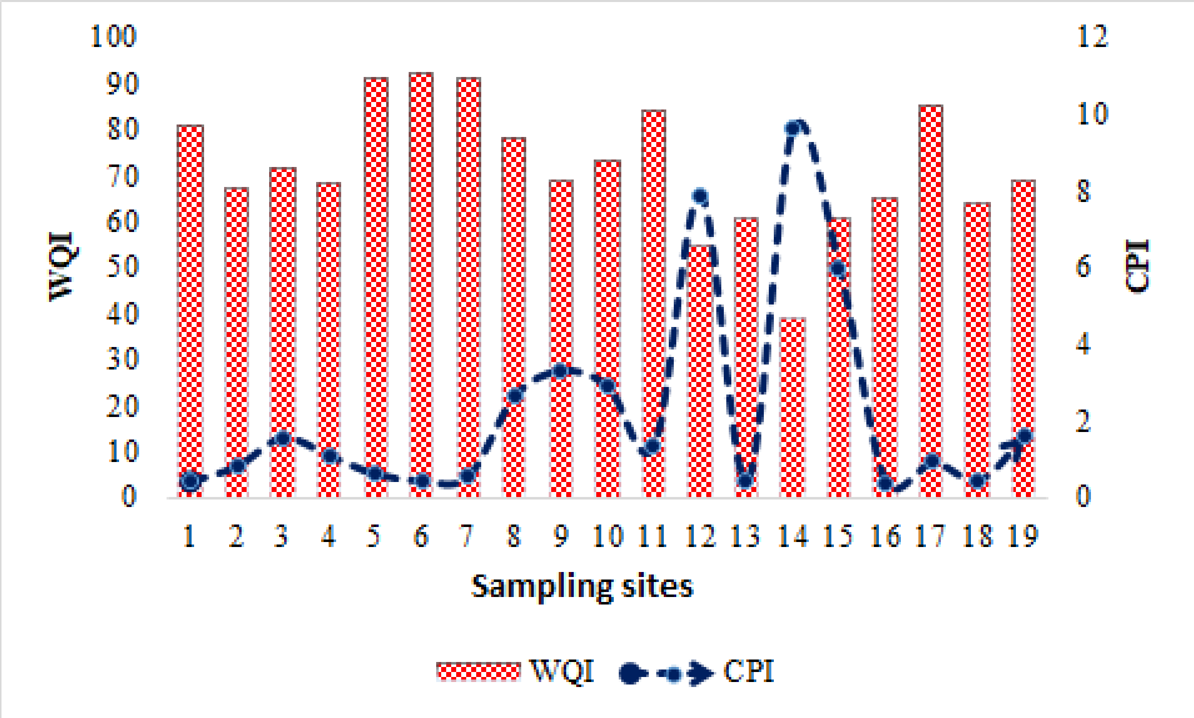

Figure 8. WQI and CPI results of the study area.

Table 6. WQI and CPI results obtained in the study

Sampling sites	CPI	Sampling sites	WQI
1	0.43 (slightly polluted)	1	80.59 (good)
2	0.82 (slightly polluted)	2	67.06 (medium)
3	1.57 (medium polluted)	3	71.76 (good)
4	1.10 (medium polluted)	4	68.24 (medium)
5	0.62 (slightly polluted)	5	91.18 (excellent)
6	0.44 (slightly polluted)	6	92.35 (excellent)
7	0.56 (slightly polluted)	7	91.18 (excellent)
8	2.66 (heavily polluted)	8	78.24 (good)
9	3.31 (heavily polluted)	9	68.82 (medium)
10	2.92 (heavily polluted)	10	72.94 (good)
11	1.36 (medium polluted)	11	84.12 (good)
12	7.90 (heavily polluted)	12	54.71 (medium)
13	0.43 (slightly polluted)	13	60.59 (medium)
14	9.62 (heavily polluted)	14	38.82 (bad)
15	5.98 (heavily polluted)	15	60.59 (medium)
16	0.39 (Sub clean)	16	65.29 (medium)
17	0.93 (slightly polluted)	17	85.29 (good)
18	0.46 (slightly polluted)	18	64.12 (medium)
19	1.59 (medium polluted)	19	68.82 (medium)

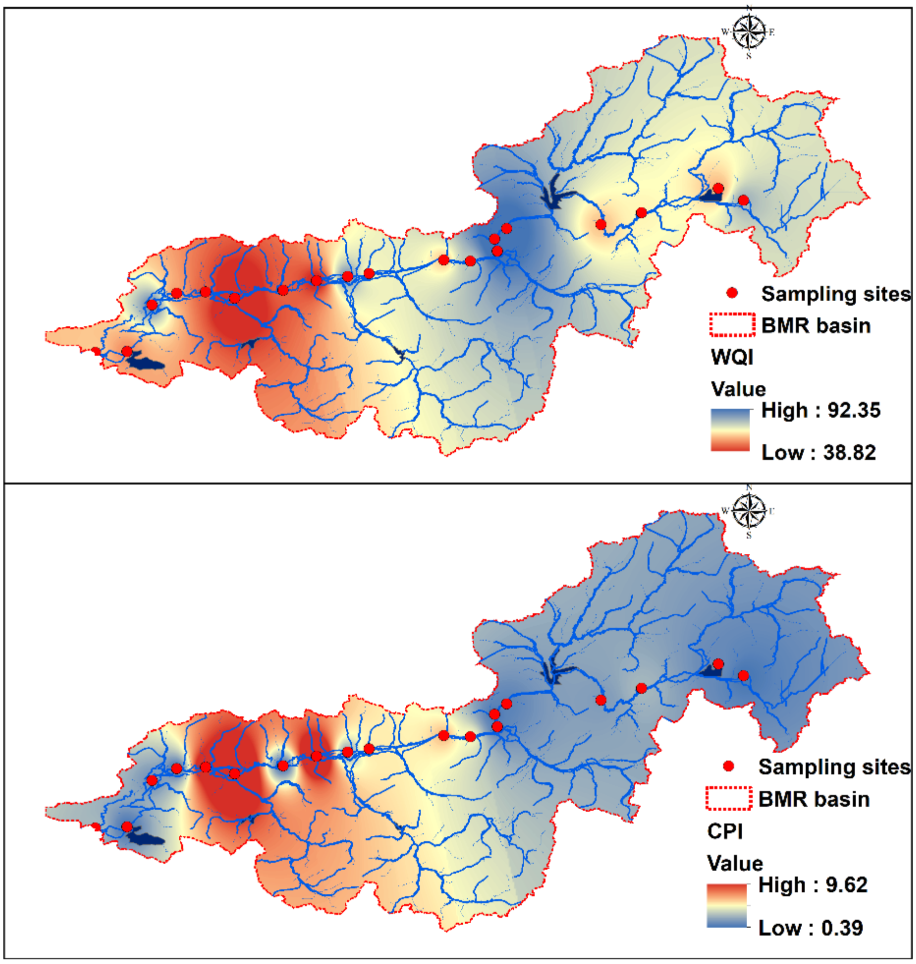

Figure 9. GIS maps of WQI and CPI results.

In this study, WQI and CPI indices were used as dependent variables and water quality parameters were used as independent variables in MLR analysis. With the calculated WQI and CPI values, the WQI and CPI values that can be created as a model can be estimated. In addition, MLR is effective in determining the parameter that most affect the change in water quality. WQI and CPI model summary obtained in the basin is given in Table 7 and Table 8.

Table 7. Model Summary of WQI (BMR).

Model Summary[f]						
Model	**R**	**R^2**	**Adjusted R^2**	**Std. EE**	**Durbin-Watson**	**ANOVA[f] WQI (BMR)**
1	0.756[a]	0.572	0.564	0.0959896		0.000[a]
2	0.965[b]	0.932	0.929	0.0387152		0.000[b]
3	0.980[c]	0.961	0.959	0.0295758	1.96	0.000[c]
4	0.986[d]	0.972	0.970	0.0250531		0.000[d]
5	0.988[e]	0.976	0.974	0.0236260		0.000[e]

a-b-c-d-e-f; Predictors, (Constant): a) NH_4-N b) NH_4-N, DO c) NH_4-N, DO, COD d) NH_4-N, DO, COD, NO_2-N e) NH_4-N, DO, COD, NO_2-N, NO_3-N f) Dependent Variable: WQI (BMR)

NH_4-N by itself showed a high correlation (r=0.756, r=0.916) with WQI and CPI according to the model summary (Table 7 and Table 8). This shows that among the measured parameters, the most important parameter affecting WQI and CPI in the basin is NH_4-N. Intensive agricultural activities in the region, domestic and industrial wastes, use of agricultural fertilizers and pesticides and other discharges are thought to be effective in the increase of NH_4-N. Potential pollutants added to the river water as a result of these activities may progress in the basin and reach the marine area.

Table 8. Model Summary of CPI (BMR).

Model Summary[e]						
Model	R	R^2	Adjusted R^2	Std. EE	Durbin-Watson	ANOVA[e] **CPI (BMR)**
1	0.916[a]	0.838	0.835	0.3026464	1.969	0.000[a]
2	0.932[b]	0.868	0.863	0.2756120		0.000[b]
3	0.980[c]	0.961	0.958	0.1519576		0.000[c]
4	0.983[d]	0.967	0.964	0.1412761		0.000[d]

a-b-c-d; Predictors, (Constant): a) NH_4-N b) NH_4-N, NO_2-N c) NH_4-N, NO_2-N, TP d) NH_4-N, NO_2-N, TP, COD e) Dependent Variable: **CPI (BMR)**

It is seen that there are significant relationships from model to model (p=0.000, Table 6 and Table 7). Considering the independent variable values, the following regression equations for WQI and CPI were obtained mathematically (r=0.988, r=0.983).

WQI(BMR)=3.2-0.4NH_4-N+0.08DO-0.02COD-0.07NO_2-N-0.04NO_3-N

CPI(BMR)=-0.60+0.82NH_4-N+1.85NO_2-N+1.10TP+0.03COD

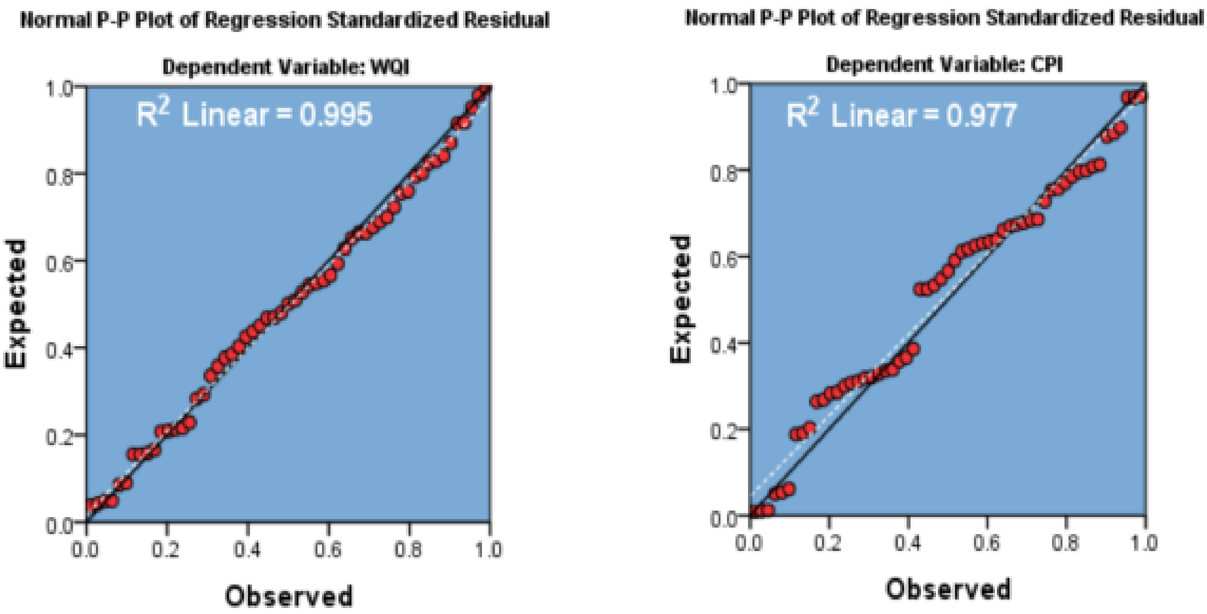

Figure 10. Graphic distribution of observed and predicted WQI-CPI values (Normal p-p plot of regression standardized residual).

The appearance of the WQI-CPI created as a model and the calculated WQI-CPI values are shown in Figure 10. In this graph, where the normality of the residual values is tested, it is seen that the calculated and estimated WQI values are quite close to each other (r^2=0.995, r^2=0.977). Since the calculated and predicted values are r^2>0.97, the graphs created show that the WQI and CPI models are important.

4. CONCLUSION

It is very important to determine and monitor the water quality of the BMR basin, which is one of the most important rivers of Türkiye. When the study area is evaluated in terms of water quality, it can be divided into three regions. The first region is rural and quieter, the second region is under the influence of more than one activity and is more affected, while the third region is close to the marine area and represents mostly agricultural work. However, it is thought that many natural and wastewater pollutants that reach the marine area by merging with the mainstream may influence the parameters. In our study, according to TWPCR (2023), it was determined that more than one parameter was in the second class, NH_4-N and TP were in the third class water quality. It was determined that there was an obvious detergent contamination especially at the sampling point fourteen (Entrance of Aydın city center). WQI and CPI were used since different water quality parameters create confusion in interpretation. WQI values were determined as “Bad-excellent” in the basin, and CPI was determined between “Sub clean and heavily polluted”. Spatial distribution maps in GIS were found to be effective in interpretation. However, it is thought that CPI values and maps give more understandable and certain results. By creating a model with MLR analysis, it was determined that the most important parameter affecting the indices was NH_4-N. As a result of the conducted analyses and calculations, it is thought that the region is under potential environmental risks.

According to the results obtained, it is seen that BMR, which is located in a very large basin, is under the pressure of many pollutants, especially agricultural, industrial, and domestic pollutants. In order to prevent risks and potential pollution in this area, integrated basin management should be established and carried out effectively with relevant institutions and organizations.

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CONFLICT of INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

Nigar Zeynalova, Mustafa Döndü, and Feyyaz Keskin performed the sample collection, laboratory process, interpretation of the data, and writing the paper. Ahmet Demirak contributed to sample collection, supervision, interpretation of the data, methodology, and writing-review & editing paper.

ETHICAL STATEMENTS

Not applicable.

DATA AVAILABILITY STATEMENT

The data used during the current study are available from the corresponding author on a reasonable request.

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