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Assessment of eutrophication in the Berdan River Basin (Türkiye) using various classification tools

by

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Abstract

The trophic status of the Berdan River Basin was determined using univariate and multivariate classification tools. The results indicated that the water quality/trophic status of a downstream section of the Berdan River was characterized as "poor/eutrophic" due to anthropogenic inputs from agricultural, industrial and domestic wastewater discharges. Strong and positive correlations between TRIX values and concentrations of eutrophication parameters suggest that nutrient enrichment of water in the Berdan River during its flow will result in further eutrophication in the coastal region of the NE Mediterranean Sea. Therefore, the trophic and pollution status of the Berdan River, as well as other regional rivers flowing into the coastal area of the NE Mediterranean Sea should be monitored to develop action plans and sustainable management of eutrophication in regional rivers and the oligotrophic Mediterranean Sea.

Key words: Trophic status assessment, eutrophication, Berdan River, Northeastern Mediterranean Sea

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1. Introduction

Transitional water systems, including lagoons, streams, estuaries and rivers are ecologically and economically important aquatic ecosystems with high productivity and high biodiversity (Caruso et al. 2010; Demir-Yetis et al. 2014). These vulnerable ecosystems and their functioning are adversely affected by anthropogenic pressures (Caruso et al. 2010). Therefore, extensive monitoring studies are being conducted to assess the trophic status of these aquatic environments (Dodds et al. 1998). Assessment of water quality in rivers and streams also contributes to coastal management of marine environments as these waters flowing to coastal sites have a major impact on ecosystem dynamics (Paula Filho et al. 2020).

Even though the Eastern Mediterranean Sea is one of the least productive seas in the world, eutrophic conditions have occurred in coastal areas of the Northeastern (NE) Mediterranean Sea due to river and wastewater discharges (Siokou-Frangou et al. 2010; Tugrul et al. 2016, 2018; Akcay et al. 2022). The Berdan River, about 124 km long, flows through the Tarsus district of Mersin. It is one of the important regional rivers flowing into the coastal region of the NE Mediterranean Sea. The Berdan River is a major source of water supply used for many purposes, such as drinking water, domestic use, agricultural irrigation and electricity generation. However, the waters of the Berdan River are heavily polluted by wastewater discharges originating mainly from industrial and agricultural activities, resulting in increased algal production (in terms of Chlorophyll-*a*) and eutrophication of the less saline coastal waters of the NE Mediterranean Sea (Kocak et al. 2010; Özbay et al. 2012; Akcay et al. 2022).

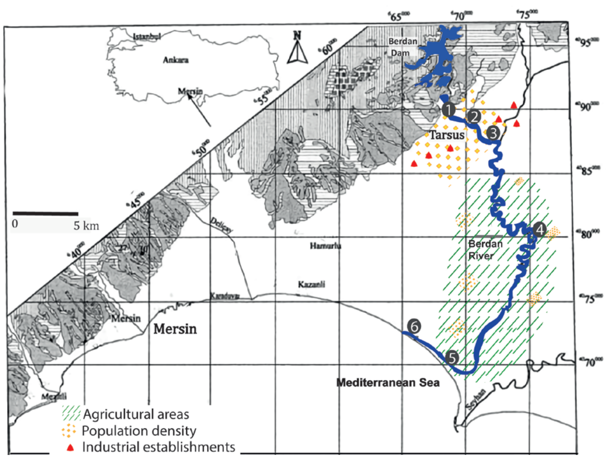

Figure 1

Sampling locations in the Berdan River Basin.

Access to safe water is essential to sustain human life, aquatic ecosystems and socio-economic development. For the health of the ecosystem and sustainable management of the Berdan River and the NE Mediterranean coastal waters, it is necessary to determine the trophic status of the Berdar River Basin. This study, therefore, aimed to assess the trophic status of the Berdan River Basin based on various eutrophication classification tools. In order to understand the impacts of anthropogenic pressures on the quality of water in the Berdan River, the spatial extent of the trophic status throughout the river basin was also determined.

2. Materials and methods

2.1. Sampling and analysis

In this study, six sites were visited monthly between December 2008 and November 2009 to determine the physical [temperature (T), salinity (S), total suspended solid (TSS)] and biochemical [nutrients: nitrogen (N) and phosphorus (P), chlorophyll-*a* (Chl-*a*) and dissolved oxygen (DO)] properties related to eutrophication of water in the Berdan River throughout the basin (Fig. 1).

Temperature, salinity and dissolved oxygen measurements were carried out in situ using a WTW 304i multimeter. For Chl-*a* and TSS measurements, surface water samples obtained from the selected sites were transferred to the laboratory, filtered through Whatman glass microfiber (GF/C) filters and stored frozen until analysis. TSS values were determined by the gravimetric method after drying the filtered samples at 105°C for 24 h (APHA 1998). Chl-*a* concentrations were determined by the spectrophotometric method after digestion of filtered samples with 90% (v v^{-1}) acetone solution (APHA 1998). Total nitrogen (TN) and total phosphorus (TP) samples were digested with microwaves after adding persulfate to the samples (Valderrama 1981; APHA 1998). TN and TP were then measured using standard colorimetric methods as described by APHA (1998). All spectrophotometric measurements were carried out using a SHIMADZU UV-VIS 1240 model spectrophotometer.

2.2. Trophic status assessment

In this study, the trophic status of the Berdan River Basin was determined using various classification tools proposed by Dodds et al. (1998) and Paula Filho et al. (2020). Dodds et al. (1998) proposed univariate scales based on concentrations of TN, TP and Chl-*a* (Table 1). Furthermore, the classification of the Berdan River Basin was assessed using the Trophic Index (TRIX) proposed by Vollenweider et al. (1998). The modified TRIX scale for river water, proposed by Paula Filho et al. (2020), was used in this study. The multivariate TRIX index was calculated using the following equation:

TRIX = log [Chl-*a* x D%DO x TN x TP] - [3.7]/0.41

where TN, TP and Chl-*a* are the concentrations in μg L^{-1}, and D%DO is the absolute deviation of dissolved oxygen from 100% oxygen saturation.

deposition (Verep et al. 2005; Tepe et al. 2006). Mean values of total suspended solids (TSS) ranged between 1.20 and 343 mg l^{-1}. Maximum TSS values were recorded at St. 2 (mean TSS: 64.64 mg l^{-1}) due to the presence of a waterfall that increases the resuspension of particulate matters across the sediment–water interface.

It is well known that total phosphorus (TP) concentrations in aquatic environments with low rates of primary production are below 5 μg l^{-1} (Wetzel 2001). TP concentrations recorded in different river basins ranged from 51.5 to 6890 μg l^{-1}, with the highest

Table 1

TN, TP, Chl-a concentration and TRIX ranges for the assessing the trophic status of stream waters

Trophic Status	TN (μg l^{-1})[a]	TP (μg l^{-1})[a]	Chl-*a* (μgl $^{-1}$)[a]	TRIX[b]
ultra oligotrophic/excellent	< 700	< 25	< 10	< 2
oligotrophic/high				2 – 4
mesotrophic/good	700 – 1500	25 – 75	10 – 30	4 – 5
mesotrophic to eutrophic/moderate				5 – 6
eutrophic/poor	> 1500	> 75	> 30	> 6

[a] Dodds et al. (1998); [b] Paula Filho et al. (2020)

3. Results and Discussion

3.1. Spatial distributions of physical and eutrophication parameters

Measurements of the main physical (T, S, TSS) and biochemical (nutrients, Chl-*a*, dissolved oxygen) parameters were carried out in the Berdan River Basin to assess water quality. The mean values and ranges of the related parameters presented in Table 2 show marked spatial and temporal variability in the study region. The mean salinity values ranged from 0.13 at the exit of the Berdan dam to 0.53 in the downstream section of the Berdan River due to the influx of the saline NE Mediterranean Sea (Table 2). Similar spatial variability was also observed for temperature values, with the maximum values recorded in the downstream section of the Berdan River (Table 2). Minimum values of temperature and salinity were recorded in winter and spring, when the largest volumes of fluxes were observed due to wet atmospheric deposition (rainfall). The results of the study indicate that the values and temporal variations of physical parameters (T, S) were consistent with the results of recent studies performed in river basins (Egemen & Sunlu 1999; Topalián et al. 1999; Gedik et al. 2010; Özbay et al. 2012). The distribution of suspended solids in river and stream waters is highly affected by particulate material carried by anthropogenic pollution and atmospheric

concentrations measured during wet winter and spring periods due to increased rainfall and volume fluxes (Bakan & Şenel 2000; Biggs 2000; Gündoğdu & Turhan 2004; Gündoğdu & Kocataş 2006; Varol et al. 2010). In this study, the measured concentrations of total phosphorus varied spatially and temporally between 16.41 and 3887 μg l^{-1}, with the maximum concentrations recorded in the downstream section of the Berdan River during the wet winter/spring period. Spatial variability of TP concentrations showed that TP values increased from the exit of the Berdan dam to the downstream section of the Berdan River, suggesting an increase in the phosphorus content of river water. The likely source of this phosphorus enrichment appears to be organic phosphorus from agricultural, industrial and domestic wastewater discharges, as also found in studies by Kronvang et al. (1999) and Karageorgis et al. (2003).

The source and origin of total nitrogen (TN) in polluted aquatic environments are mainly agricultural sources of nitrogen (Kronvang et al. 1999). TN concentrations in river and stream waters varied between 163 and 38,500 μg l^{-1} (Biggs 2000; Fytianos et al. 2002; Bellos et al. 2004; Bulut et al. 2010; Varol et al. 2010). In this study, TN concentrations ranged from 184.7 at St.2 to 7596 μg l^{-1} at St. 4 (Table 2). The highest mean TN values were recorded at St. 4, 5 and 6 in winter and spring due to nitrogen inputs from agricultural, industrial and domestic wastewater discharges (Table 2).

Table 2

Measurements of physical (T, S, TSS) and biochemical variables (nutrients, Chl-*a*, dissolved oxygen) and calculated TRIX values for the selected sites in the Berdan River Basin

Site		TSS (mg l^{-1})[a]	DO (mg l^{-1})[a]	T (°C)[a]	S[a]	DO (% sat.)[a]	TN (µg l^{-1})[a]	TP (µg l^{-1})[a]	Chl-*a* (µg l^{-1})[a]	TRIX[a]	NO_3 (µM)[b]	PO_4 (µM)[b]	N/P (molar)[a]
1	Average	28.80	9.06	15.62	0.13	90.84	1709.36	72.37	4.58	5.71	39.84	0.55	72.18
	min. – max	1.20 – 124.60	7.13 – 10.90	10.30 – 21.80	0.10 – 0.20	75.64 – 108.48	259.6 – 7225.69	34.53 – 216.21	0.27 – 15.94	4.11 – 7.98	31.06 – 62.91	0.02 – 2.20	
2	Average	64.64	9.59	15.79	0.14	96.50	1588.23	49.58	1.83	4.30	41.16	0.55	75.48
	min. – max	2.80 – 343.00	7.22 – 13.50	10.30 – 21.60	0.10 – 0.20	79.73 – 125.56	184.70 – 7383.61	16.41 – 113.61	0.52 – 6.30	0.52 – 8.54	27.12 – 61.68	0.01 – 3.51	
3	Average	19.15	8.95	15.82	0.14	89.81	1752.42	99.86	1.50	5.20	52.78	0.57	92.76
	min. – max	1 – 62.20	5.10 – 13.15	9.60 – 21.80	0.10 – 0.20	56.32 – 119.46	239.26 – 7376.16	25.47 – 262.16	0.76 – 2.48	0.18 – 9.69	30.07 – 145.07	0.01 – 1.70	
4	Average	23.15	8.58	16.83	0.21	87.68	2238.07	763.77	2.96	8.52	82.17	7.60	10.81
	min. – max	1 – 61.00	6.20 – 11.70	9.80 – 27.20	0.10 – 0.30	68.46 – 110.59	556.13 – 7596.10	84.90 – 3831.19	1.13 – 6.61	5.12 – 13.51	47.08 – 230.30	0.18 – 25.95	
5	Average	34.55	7.66	17.61	0.36	79.78	2322.96	754.19	3.64	9.51	81.57	6.98	11.69
	min. – max	2 – 108.40	5.29 – 11.90	10.30 – 27.40	0.10 – 1.10	57.20 – 110.68	523.26 – 7569.67	109.80 – 3803.99	1.13 – 6.98	7.50 – 14.14	49.93 – 161.50	0.30 – 29.86	
6	Average	26.40	7.18	17.63	0.53	76.28	2210.73	747.96	7.07	9.60	74.41	6.96	10.70
	min. – max	2.40 – 69.40	5.40 – 9.74	10.30 – 28.70	0.10 – 2.30	49.63 – 107.03	509.03 – 7557.47	123.96 – 3887.10	0.88 – 31.71	6.07 – 14.27	34.45 – 156.19	0.36 – 27.69	

[a]This study; [b]Özbay et al. (2012)

Regional and temporal/seasonal variations in dissolved nutrient (phosphate and nitrate) concentrations measured in the study area were very similar to spatial and temporal variations in total phosphorus and nitrogen concentrations (Table 2). Özbay et al. (2012) reported that PO_4 concentrations varied between 0.01 and 29.9 µM, while NO_3 concentrations ranged from 27.1 to 161.5 µM. The maximum values were recorded during wet winter and spring periods. In this study, mean molar ratios of N/P were calculated from the mean values of nitrate and phosphate, and ranged from 10.7 at St. 6 to 92.8 at St. 3. The higher N/P molar ratios at St. 1, 2 and 3 compared to the Redfield ratio (N/P = 16) suggested that algal production in these regions was primarily limited by phosphorus. Both higher phosphorus concentrations and low N/P molar ratios at St. 4, 5 and 6 strongly suggested that P-enrichment in the water of the Berdan River during its flow was due to agricultural, industrial, and domestic wastewater discharges. Recent studies performed in the downstream section of the Berdan River also found similar phosphorus enrichment increasing primary productivity at the coastal sites of the NE Mediterranean Sea, affected by the Berdan River inflows (Tuğrul et al. 2007, 2009, 2011, 2016; 2019; Kocak et al. 2010).

Dissolved oxygen (DO) concentrations and DO saturation levels showed high spatial and temporal variability in the study region (Table 2). DO concentrations ranged from 5.10 mg l^{-1} (56.3% sat.) to 13.5 mg l^{-1} (125.6% sat.). As expected, the maximum DO concentrations were measured in regions with lower temperature and salinity values (Table 2). Concentrations of chlorophyll-*a* (Chl-*a*), an indicator of primary productivity, in the Berdan River Basin varied between 0.27 and 31.7 µg l^{-1}, with the highest concentrations measured in the downstream section of the Berdan River due to nutrient enrichment, as well as a decrease in the volume of fluxes in this region (Table 2). Chl-*a* concentrations in rivers can reach 250 µg l^{-1} and are strongly increased by elevated solar radiation and temperature (Biggs 2000; Wetzel 2001; Kayaalp & Polat 2001; Odabaşı & Büyükateş 2009). The regional variability of Chl-*a* concentrations in the Berdan River Basin was similar to that observed in previous studies, with maximum values measured in the downstream sections of the studied rivers (Kayaalp & Polat 2001; Türkoğlu et al. 2004; Odabaşı & Büyükateş 2009).

3.2. Assessment of the trophic status of the Berdan River Basin

To determine the trophic status of the Berdan River Basin, six sites located throughout the basin were visited monthly. Trophic conditions of the visited sites were determined using two different eutrophication classification tools (Figs 2 and 3). According to the classification method for assessing stream water quality proposed by Dodds et al. (1998), the mean annual concentrations of TN, TP and Chl-*a* were used and presented in Figure 2. Trophic status classification based on TN, TP and Chl-*a* values showed that the water quality in the Berdan River varied from "oligotrophic" to "eutrophic" during its flow through the Berdan River Basin. Eutrophic conditions resulted from anthropogenic inputs originating from agricultural, industrial and domestic wastewater discharges (Fig. 2). Nutrient enrichments and increasing rates of algal production (in terms of Chl-*a*) have led to water eutrophication in the Berdan River in the downstream reaches. Thus, the waters of the Berdan River feeding the NE Mediterranean shelf region have led to coastal eutrophication in the NE Mediterranean Sea, as previously reported in the studies by Dogan-Sağlamtimur &Tugrul (2004), Tugrul et al. (2016), Tugrul et al. (2019) and Akcay et al. (2022).

The results of the study strongly suggest that the classification method and limit values proposed by Dodds et al. (1998) may not be applicable to assessing water quality in the Berdan River Basin due to its low sensitivity. It is also considered that the univariate scales based on a single variable, TN, TP and Chl-*a* in this study, may not be adequate to describe the trophic status of the Berdan River. Therefore, this study followed a multi-parameter approach to assess the water quality in the Berdan River Basin using the Trophic Index (TRIX) proposed by Vollenweider et al. (1998). The TRIX scale and limit values, developed to assess water quality in the Adriatic Sea, were modified by Paula Filho et al. (2020) to assess the trophic status of river waters. Based on this modified multimetric TRIX index, which fits the five ecological status classes stipulated by the Water Framework Directive, the waters of the Berdan River were characterized as waters of "good" to "poor" quality (Fig. 3). Strong

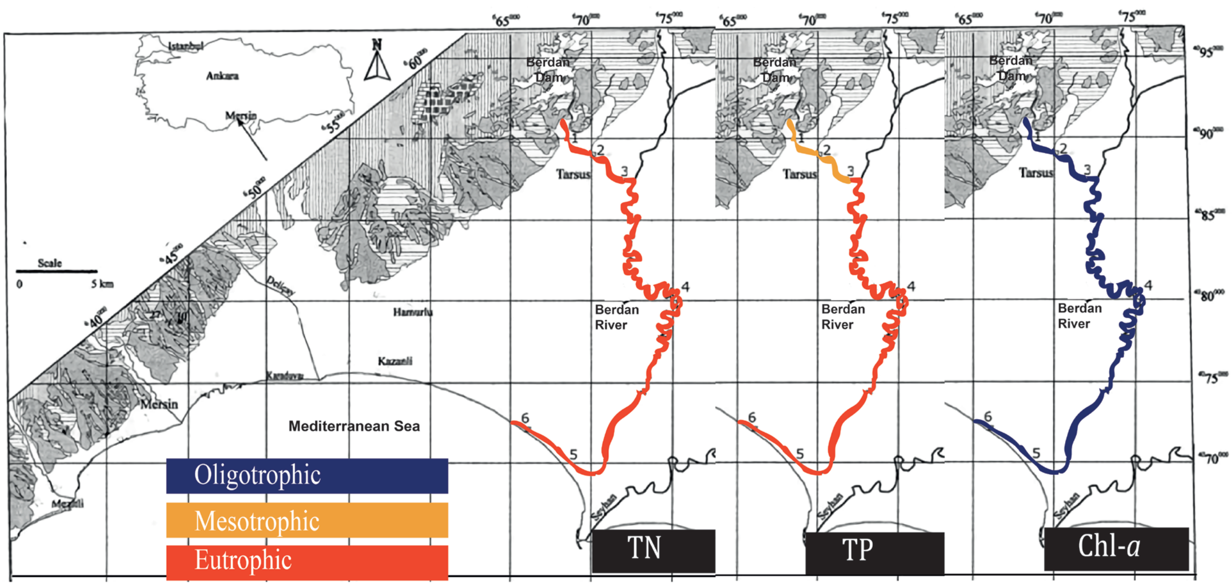

Figure 2

Assessment of the trophic status of the Berdan River Basin based on TN, TP and Chl-*a* concentrations according to Dodds et al. (1998).

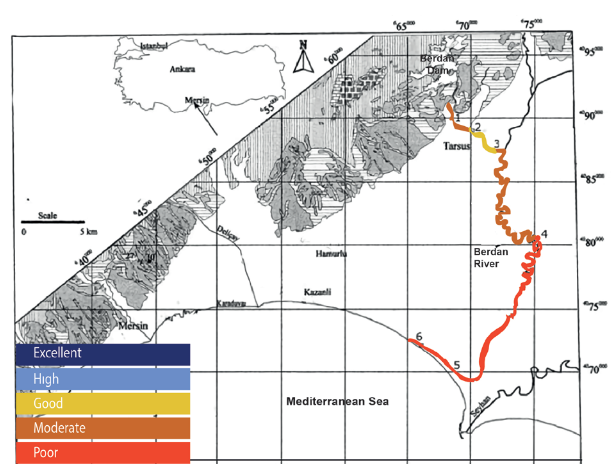

Figure 3

Trophic status assessment of the Berdan River Basin based on TRIX values.

correlations between TRIX and eutrophication parameters indicate that the multimetric TRIX scale is sensitive in determining the final trophic status of the Berdan River Basin (Fig. 4). Similar to the spatial variability in eutrophication parameters (Table 2), the mean TRIX values suggest that the waters in the Berdan River are heavily contaminated by agricultural, industrial, and domestic wastewater discharges during its flow, leading to eutrophication in the downstream reaches of the river. Positive correlations between TRIX values and concentrations of nutrients and Chl-*a* suggest that further nutrient enrichment and increasing rates of primary productivity would increase eutrophication in the downstream reaches of the Berdan River, leading to further eutrophication in the coastal region of the NE Mediterranean Sea.

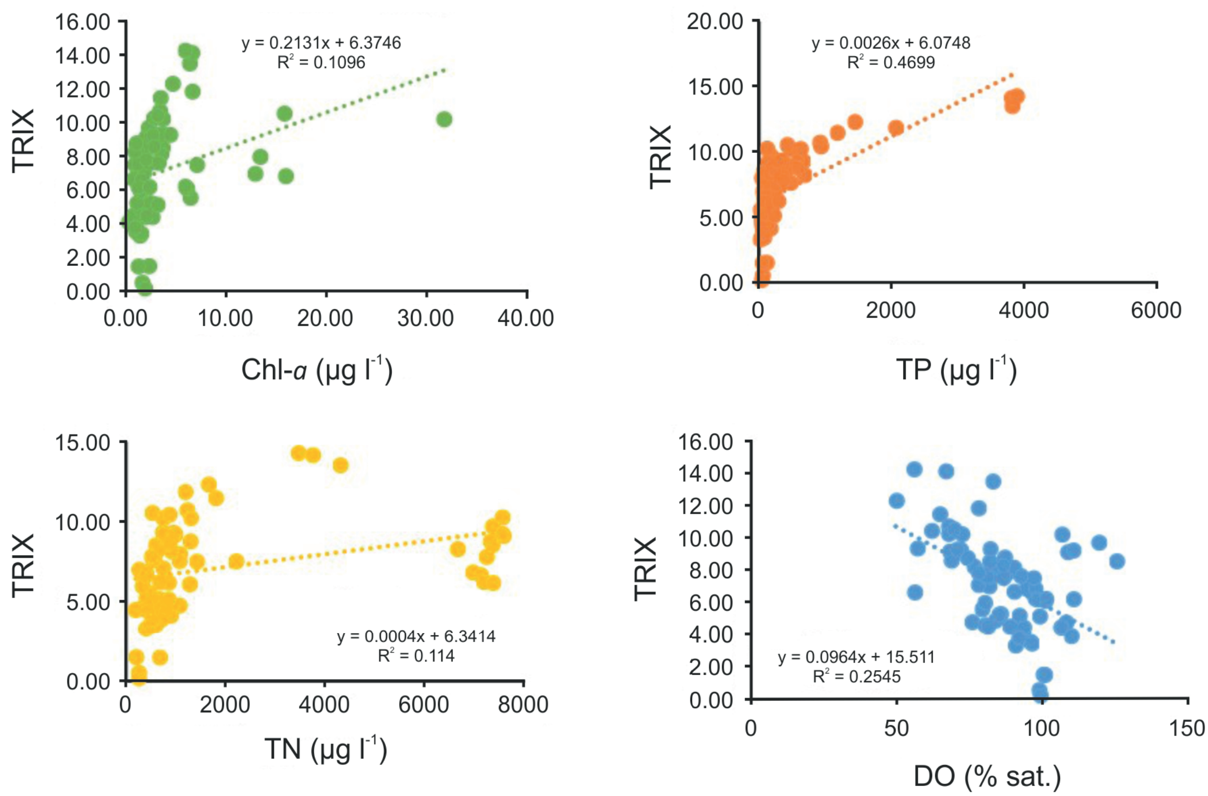

Figure 4

Correlations between TRIX and eutrophication parameters.

4. Conclusions

In this study, physical and biochemical parameters of eutrophication were determined to assess water quality in the Berdan River Basin. The eutrophication status of the Berdan River Basin was assessed using univariate and multimetric classification tools. The results of the study show that the parameters indicating eutrophication varied considerably over space and time in the study region. Maximum concentrations of TN and TP were consistently recorded in the downstream stretch of the Berdan River, which significantly increased primary production (in terms of Chl-*a*) and eutrophication. Based on this study, the water quality / trophic status of the downstream section of the Berdan River was characterized as "poor/eutrophic" due to anthropogenic inputs from agricultural, industrial and domestic wastewater discharges. Strong and positive correlations between TRIX values and concentrations of nutrients and Chl-*a* suggest that nutrient enrichment in the Berdan River during its flow would further increase eutrophication in the coastal region of the NE Mediterranean Sea, where oligotrophic conditions prevail in the offshore waters. Therefore, the input of organic and inorganic matter into the Berdan River, as well as other regional rivers flowing into the coastal area of the NE Mediterranean, should be reduced in order to sustainably manage eutrophication in regional rivers and the oligotrophic Mediterranean Sea.

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Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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