https://doi.org/10.17221/142/2022-SWR

Assessment of old eutrophication in the sediments of Marchica Lagoon (a post-restored lagoon, Mediterranean): The role of geochemistry and granulometry of the sediments

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Citation: Rahhou A., Layachi M., Akodad M., El Ouamari N., Aknaf A., Skalli A., Loukili H., Bernichi Y., Oudra B., Baghour M. (2023): Assessment of old eutrophication in the sediments of Marchica Lagoon (a post-restored lagoon, Mediterranean): The role of geochemistry and granulometry of the sediments. Soil & Water Res., 18: 169–180.

Abstract: The aim of this study is to present the seasonal variation of organic matter (OM), total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP) in the bottom sediments of Marchica Lagoon, a post-restorated lagoon located in the Moroccan Mediterranean, and to estimate the potential role of the geochemistry and granulometry of bottom sediments in the retention of old eutrophication. The organic index of bottom sediment was found generally higher in old-eutrophic and enclosed areas. The surface sediments show variable levels of OM, TOC, TP, and TN; high in some cases (12.3%, 6.71%, 0.70%, and 0.30% respectively). These high levels were recorded in the central part of the lagoon and in areas subjected to high anthropogenic pressure, including wastewater discharges. Our results indicated that sediments are an excellent immobilizer of organic matter (C, N, and P), although, there was no correlation between sediment grain size and organic matter content. The absence of correlation might be explained by currentology and hydrodynamics, but also by the bathymetry of the lagoon. Therefore, sediments must be implicated in any lagoon restoration strategy and the site development plan.

Keywords: grain size; nitrogen; organic index; organic matter; phosphorus

Coastal lagoons are highly dynamic environments in terms of biogeochemistry, and they play an important role in the transport, modification and accumulation of organic matter at the land-ocean interface. Due to their proximity to the coast, lagoons receive considerable amounts of nutrients, which stimulate in situ primary production by microphytobenthos, macroalgae and seagrass meadows (Bianchi 2007). Globally, regions with rapid population growth, excessive discharges of human sewage, and/or the extensive use of synthetic fertilizers as a result of industrial agriculture have all been shown to have high characteristics of coastal eutrophication (Howarth 2008; Malone & Newton 2020). Combining these factors

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makes such systems more susceptible to eutrophication and promotes the deposition of organic matter and pollutants in sediment (Pereira et al. 2010). Eutrophication is a global problem characterized by high loads of nitrogen and phosphorus in waters and results in excessive growth of phytoplankton and other aquatic plants (Schindler et al. 2008). Recent decades have seen an increase in nutrients in the estuary and coastal water due to both anthropogenic activity and climate change (Zhang et al. 2020). Coastal lagoons typically exchange part of their water with the sea, either regularly or intermittently, through a restricted inlet in the sand barrier. In addition, coastal lagoons conditions can be impacted by both freshwater and sediment inputs from the watershed river (Katsuki et al. 2019). The changes in water quality and ecosystem status in a lagoon modify the chemical and mineral characteristics of the lagoon. Therefore, past water quality and ecosystem factors can be recovered from the analysis of these components in the lagoon bottom sediments (Weckström et al. 2017). When pollutants enter aquatic ecosystems, they can be sorbed to the bottom sediment. These sediments can be a further source of contaminants to the surrounding waters (Wu et al. 2001; Jin et al. 2006). Among these pollutants, the geochemistry (C, N, and P) of sediment is affected by algal production in coastal surface waters, sediment re-suspension, and organic matter degrading mechanisms at the sediment-water interface (Jørgensen 1996).

Mediterranean coastal lagoons are generally surrounded by heavily populated urban areas and are therefore subject to great anthropogenic impacts, including elevated domestic wastewater inputs (Viaroli et al. 2008; Souchu et al. 2010).

The study of restoration pathways is relatively new (Duarte et al. 2009; Leruste et al. 2016; De Wit et al. 2017) and many efforts have been made in many aquatic ecosystems to reduce external nutrient loading by applying best management practices in the watershed, but, their restoration has been delayed for years due to the release of bottom sediments to the water column, a phenomenon known as internal loading (Søndergaard et al. 2003).

Due to the importance of coastal lagoons, their biodiversity, and their fluctuations, it is essential to study these ecosystems' geological, biological, and environmental characteristics and understand their evolution. Identifying the different threats and pressures, their sources, their origins, and impacts on the functioning of these ecosystems and their components allow the design and implementation of appropriate strategies for adequate management.

In this regard, prior to the restoration of the lagoon, studies on the hydrography, the biological and chemical characteristics of the water, and the sediments of the Marchica Lagoon were conducted (Ruiz et al. 2006; Bloundi et al. 2008), and other studies on the quality of the waters during the post-restoration period pointed on the variation of physico-chemical parameters and nutrient levels in the water (Mostarih et al. 2016; Aknaf et al. 2017; Oujidi et al. 2020). No study has been done to examine the contribution of the internal load especially nitrogenous elements; all of these studies have been conducted on water column. In order to answer the question "What is the potential of internal nutrient loading?", a detailed study of the aquatic system of interest, with emphasis on the sediments, is required. In this context the present study aims to (1) determine the seasonal and spatial variation of nitrogen, phosphorus, organic carbon and organic index in the sediments and to study the relationships between the variables and their possible distribution patterns, to focus on the quality status of the surface sediments and the role of sediment geochemistry and grain size in the sequestration process of the studied parameters. (2) to determine the sedimentary role in the recycling of nitrogen and phosphate nutrients and their contribution to the trophic status of this lagoon in the eutrophication process

MATERIAL AND METHODS

Study area. The lagoon of Marchica or Sebkha of Bouareg is located between (02°45'–02°55') and (35°16'–35°06') (Figure 1), and it's the largest and only one located along the Moroccan Mediterranean coast, with a total area of about 115 km^2 and a maximum depth of 8 m. Separating the Mediterranean Sea by a 25 km long sandbar and crossed by an artificial inlet (300 m wide and 6 m deep) to ensure the renewal of water in the lagoon (Hilmi et al. 2015; Maicu et al. 2021), it has been classified as a Site of Biological and Ecological Interest (SIBE) since 1996, and as a wetland under the international convention of Ramsar since 2005. However, this wetland is subject to both watershed pressures and land runoff from domestic, agricultural, and industrial discharges as well as pollution from waste mining (Oujidi et al. 2020). The restoration activities of the Nador Lagoon have been started in 2010, they include the set up of two wastewater treatment plants (WWTP) to reduce wastewater

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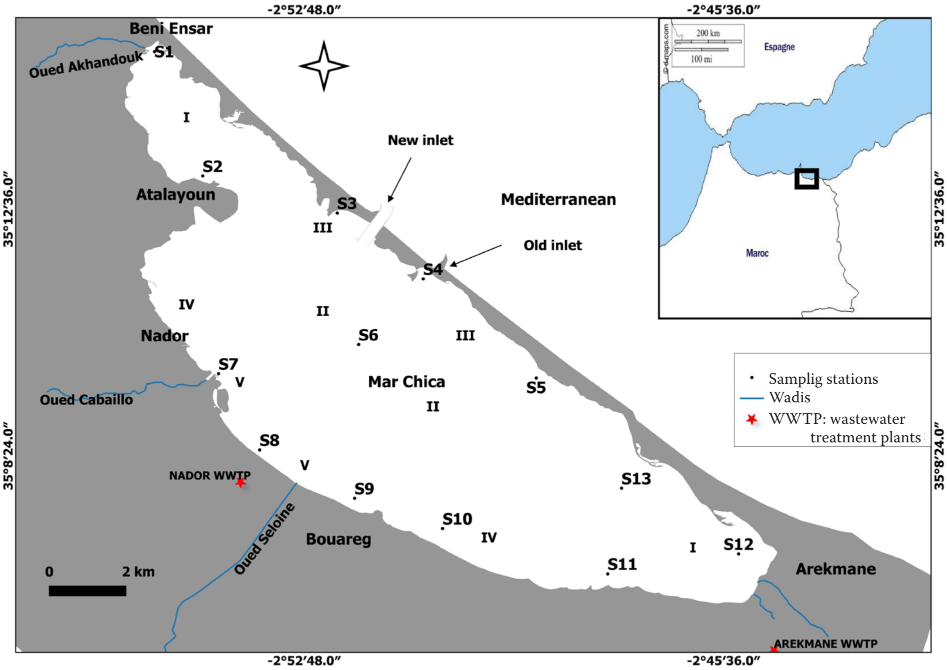

Figure 1. Location of the study area and sampling network: sampling stations (S1–S13); sedimentation zones (I–V) (Terhzaz et al. 2011)

pollution and improve sanitary conditions (WWTP of Nador in 2010 and Arekmane's WWTP in 2013), the opening of a new inlet between the lagoon and the Mediterranean Sea in 2011 to exchange water and reduce the renewal time of the lagoon's waters, and the cleaning of the lagoon's waters and its surroundings by collecting solid wastes and dredging the wadis' mouths between 2010 and 2013 (Oujidi et al. 2020). The sedimentological study of the deposits of the lagoon has identified five areas of sedimentation, ie: the inner margin of the sandbar under the marine influence, the central part of the lagoon, also under marine influence, the continental edge under the continental influence in the lagoon, two areas confined to the north-west and south-east of the lagoon, and the mouths of wadis in the continental area (Terhzaz et al. 2011).

The opening of the new inlet has significantly reduced the renewal time of the water from (25–75) days with the old inlet to (15–57) days with the new inlet (Maicu et al. 2021) and increased the exchange with the sea, so that the thermohaline characteristics of the lagoon are more similar to those of the sea. This anthropogenic change has reduced the lagoon's renewal time as the climate changes, but in a much shorter time and with greater magnitude. While, the mixing efficiency of the lagoon has not changed significantly, as it depends much more on surface boundaries (wind forcing) rather than laterals boundaries conditions (Maicu et al. 2021).

Sampling strategy. The sampling stations were established considering the sedimentological characteristics, bathymetry and currentology of the lagoon, ensuring the coverage of all areas and taking into account the potential sources of pollution: stations under marine influence and stations under the continental influence, including wadis mouths (Wadi of Cabaillo and Wadi of Selouane) and the discharge sites of wastewater treatment plants. There were 13 sampling stations within the lagoon for each sampling campaign (Figure 1). Sediments were collected by diving, using PVC tube (length 30 cm, diameter 5 cm). Samples were collected in the first 10 cm of depth and stored at a temperature of 4 °C. Samples were collected during winter (February) and summer (July) in 2020.

Nitrogen, carbon, organic matter (OM), total phosphorus (TP), and total organic carbon (TOC) were all tested in dry sediment samples. Nitrates and nitrites were analysed after extraction with a 2M KCl solution (Smart et al. 1983). The TOC content in surface sediment was determined by the method adopted by Black and Wiley (GLOSOLAN 2019), this method consists of oxidation of organic carbon present in the sediment in a mixture of a solution

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of potassium dichromate and sulphuric acid, followed by measurement of absorbance in spectrophotometer. Total nitrogen (TN) content was determined following the Smart et al. (1983) method by mineralization of sediment samples by persulfate, followed by spectrophotometer measurements (UV-VIS Spectrophotometer Pharo 300, Merck, Germany). TP content was determined following the method of Ostrofsky (2012) based on persulfate digestion and measurement by spectrophotometry (UV-VIS Spectrophotometer Pharo 300, Merck, Germany). Organic matter or loss-on-ignition (LOI) in sediment were determined in an oven at 550 °C, pH of sediment measured with pH-probe in the suspension of sediment according to (Rodier et al. 2009). To assess the combined risk of organic carbon and organic nitrogen in sediments, the status of organic matter (carbon and nitrogen) in Marchica Lagoon was investigated by the organic index (OI, Equation 1) and its associated evaluation standards are shown in (Table1) according to (Hadjispyrou et al. 1998; Cheng et al. 2021) where:

$$\text{OI} = \text{organic carbon (\%)} \times \text{organic nitrogen (\%)} \quad (1)$$

$$\text{Organic nitrogen (\%)} = \text{total nitrogen} \times 0.95 \quad \text{(Zhang et al. 2015)} \quad (2)$$

Statistic. The Mann Whitney test was used to check the effect of season, the significant differences between the mean ranks of each parameter (PT, NT, NO_3, NH_4, TOC, OM, and pH) between the two studied seasons. To investigate the relationships between the variables and their possible distribution pattern, a principal component analysis (PCA) was used, as described in other studies. The organic index values were interpolated (inverse distance weighting) on the Marchica map to show the seasonal variation of this index along the Marchica Lagoon during the study period. Normality was not verified generally (Shapiro-Wilk test, $P > 0.05$); statistical analysis was applied using Spearman's coefficient to test significant correlations between the above parameters and the geochemical characteristics and granolumetry of sediments by using data of Oujidi et al. (2021). To investigate the relationships between the variables and their possible distribution pattern, a PCA was used. The data were processed using IBM SPSS (Ver. 26) software. QGIS (Ver. 2.18) software was used to produce the maps of the lagoon.

RESULTS AND DISCUSSION

Sediment parameters variation. The results of the physico-chemical parameters are presented in Table 2. The results of pH and nitrate indicated significant variation between summer and winter ($P < 0.05$), while TOC, TN, ammonium, TP and organic matter did not indicate significant variation. pH in winter was between 7, 84 and 8, 20 and between 8.05 and 9.20 in summer. Nitrate ranged from 0.05 to 2.06 mg/kg in winter and from 0.07 to 0.38 mg/L in summer. The highest values were found at stations with continental influence (S7, S8, S9, S10, S11, and S12). In both seasons, ammonium ranged from 9.5 to 140 mg/kg, with the highest values near the wastewater outfall. Total phosphorus ranged from 0.12 to 0.705%, with the highest value in the middle of the lagoon and the lowest near the new inlet. Total nitrogen reported the highest value in the Beniensar confined area and the lowest value in the Bouareg area and ranged from 0.08 to 0.300%. Organic matter and total organic carbon ranged from 1.4 to 12.3% and 0.119% to 6.71% respectively; both, TOC and OM recorded high values in the central part of the lagoon and in the old eutrophic areas (Arekmane and Beniensar).

Compared to the results of Akrout et al. (1995), the organic matter distribution in the surface sediment of the lagoon decreased globally, including the most enclosed zones (the NW and SE borders of the lagoon), with OM decreasing from (< 5% to > 20%) in 1992 to (1.5–12.5%) in the present study. Our results are consistent with those found in 2011 (less than 5–10%) by Najih et al. (2017) with increasing values of OM in Bouareg area than those previously reported by Najih et al. (2017), and this is probably due to wastewater discharge and eutrophication

Table 1. Organic index criteria for sediment (Zhang et al. 2015)

	Organic index in surface sediment			
	< 0.05	0.05–0.2	0.2–0.5	> 0.5
Pollution level	practically uncontaminated	uncontaminated to moderately contaminated	moderately contaminated	heavily contaminated

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(Rahhou et al. 2022). This comparison clearly shows that the restoration activities started in 2010 have resulted in a considerable reduction of organic pollutants on the lagoon sediments. However, it suggests that the sedimentary process requires a long time to reach a new equilibrium. Furthermore, many factors impact organic matter content in sediments, including allochthonous discharge of organic matter and nutrients, autogenic primary productivity, diagenesis, and resuspension (Ziemińska-Stolarska et al. 2020), in addition, muddy sediments had OM content (LOI) of 20%, whereas sandy sediments had an OM content of 1% (Bartoli et al. 2021).

In our study, recorded TOC rates were slightly lower than those recorded by Bloundi et al. (2008) (up to 7.59%), consistent with those published by Oujidi et al. (2021) and higher than the results of Aknaf et al. (2022). The high values of TOC are related to hydrodynamic regime, muddy fraction; which is mostly composed of fine clay minerals with a high ability to interact with organic matter, and the strong movement of terrigenous organic matter delivered toward the lagoon, as reported by Ben Mna et al. (2021). Comparing our results with those obtained in other marine and lagoon ecosystems, the total organic carbon content of the surface sediments of Marchica lagoon was similar to, and in some cases higher than, some Mediterranean and lagoons ecosystems; in the Gulf of Tunis TOC values ranged from 0.14–12%, with lowest concentrations (0.14–2 mg/g) in the

Table 2. Results of studied parameters in winter and summer

Sampling stations	Season	$N\text{-}NO_3^-$ (mg/kg DW)	$N\text{-}NH_4^+$ (mg/kg DW)	pH	TP (% DW)	TN (% DW)	OM (% DW)	TOC (% DW)
S1	winter	0.050	9.5	7.84	0.480	0.300	2.12	1.24
S2		0.090	97	7.9	0.490	0.140	11.52	5.765
S3		0.090	10	8.04	0.185	0.041	1.4	0.333
S4		0.568	18.2	8.13	0.120	0.031	4.16	1.738
S5		0.608	14.3	8.2	0.150	0.026	1.88	1.02
S6		1.480	48.1	8	0.500	0.113	12.32	6.71
S7		1.900	23.7	7.88	0.420	0.025	2.88	0.119
S8		2.060	140	7.96	0.450	0.028	10.8	4.123
S9		1.290	19.8	8.15	0.165	0.020	1.92	0.358
S10		1.370	21	8.07	0.150	0.025	2.56	0.652
S11		1.640	38	7.9	0.325	0.090	9.04	3.54
S12		1.300	105	8.02	0.360	0.056	11.12	5.218
S13		1.440	86	8.14	0.440	0.132	11.76	4.541
S1	summer	0.225	12.5	9.2	0.457	0.068	1.64	1.282
S2		0.070	34.8	8.9	0.464	0.082	8.32	4.051
S3		0.145	12.3	8.45	0.212	0.027	1.6	0.55
S4		0.179	14.75	8.2	0.372	0.029	2.896	0.877
S5		0.149	15.75	8.1	0.223	0.025	2.4	0.702
S6		0.320	12.2	9	0.705	0.084	12.16	6.456
S7		0.330	17	8.21	0.156	0.018	1.92	0.266
S8		0.220	30.5	8.18	0.309	0.034	7.16	5.288
S9		0.255	20.15	8.24	0.302	0.028	1.88	0.463
S10		0.285	18.1	8.52	0.204	0.022	1.6	0.421
S11		0.285	17.25	8.29	0.371	0.040	9.064	3.953
S12		0.215	31.55	8.95	0.217	0.039	8.16	5.645
S13		0.380	11.35	8.05	0.312	0.029	9.84	4.351

TP –total phosphorus; TN – total nitrogen; OM – organic matter; TOC – total organic carbon

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coastal areas and highest concentrations (3–12% mg/g) were observed in open sea sediments opposite river mouths (Ben Mna et al. 2021). In Bardawil Lagoon Egypt surface sediment samples have TOC values less than Marchica Lagoon and ranging between 0.87–2.4% (Taher 2001); values of TOC in the Bizert lagoon show a mean value of 1.39 % in the lagoon core sediment and 1.66 % in open sea sediment samples (Zaaboub et al. 2014). In Algeria, the superficial sediments of the Gulf of Arzew contained between 0.2–1.2% of TOC DW (Buscail et al. 1999). In sediments of the Pearl River Estuary Huang et al. (2021) reported values 5.82 mg/g DW of total organic carbon. However, the sediment of Chilika Lagoon, recorded rates of total carbon between 0.34–1.97% (Nazneen & Raju 2017).

Our results show that total phosphorus concentrations in sediments are higher than those reported by Oujidi et al. (2021). Comparing our results with those obtained from other lagoons, TN contents in sediment of the Gulf of Tunis ranged from 0.170 to 1.46 mg/g, with an average of 0.66 mg/g, and TP contents ranged from 0.1 to 0.68 mg/g (Ben Mna et al. 2021), and in the Bizert Lagoon, phosphorus ranges from 464–619 mg/g 15–20 mmol P/g in surface core sediment (Zaaboub et al. 2014). In the Gulf of Gdansk total nitrogen, and organic phosphorus shows respectively concentrations of (0.1–14.3 mg/g DW) and (0.9–76.1 μg/g DW) (Łukawska-Matuszewska et al. 2014). In Venice Lagoon, values of TN varied between 0.9–9.8 mg/g DW, phosphorus between 20–500 μg/g DW (Markou et al. 2007). In Algeria, the nitrogen content of superficial sediments in the Gulf of Arzew ranged between 0.05–0.35% of their dry weight (Buscail et al. 1999) while in total nitrogen concentrations of surface sediment samples from Bardawil Lagoon (Egypt) varied from 0.002 to 0.046% (Taher 2001).

Correlation of organic matter, TOC, TN, TP, and groups stations. For each season, two principal components (PC) were obtained, contributing for 77.98% of the total variation in the winter (Figures 2–5) and 71.99% of the total variance in the

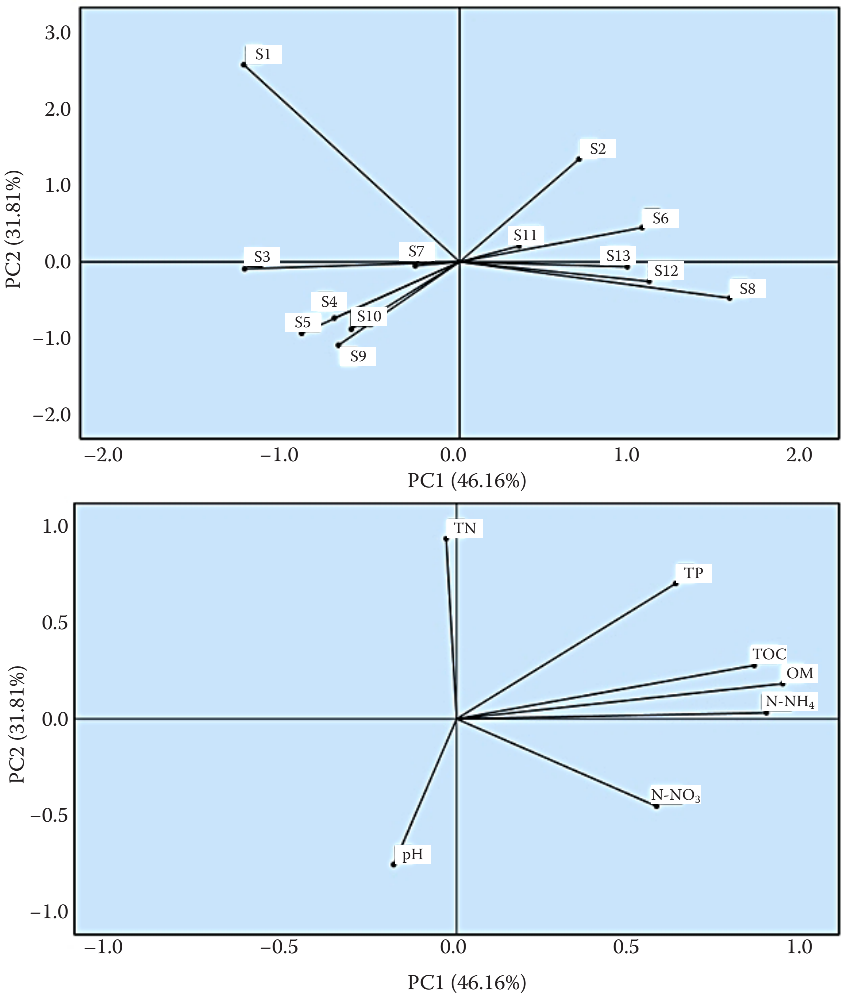

Figure 2. Principal component analysis (PCA) of the sampling stations and studied parameters in winter

TP –total phosphorus; TN – total nitrogen; OM – organic matter; TOC – total organic carbon

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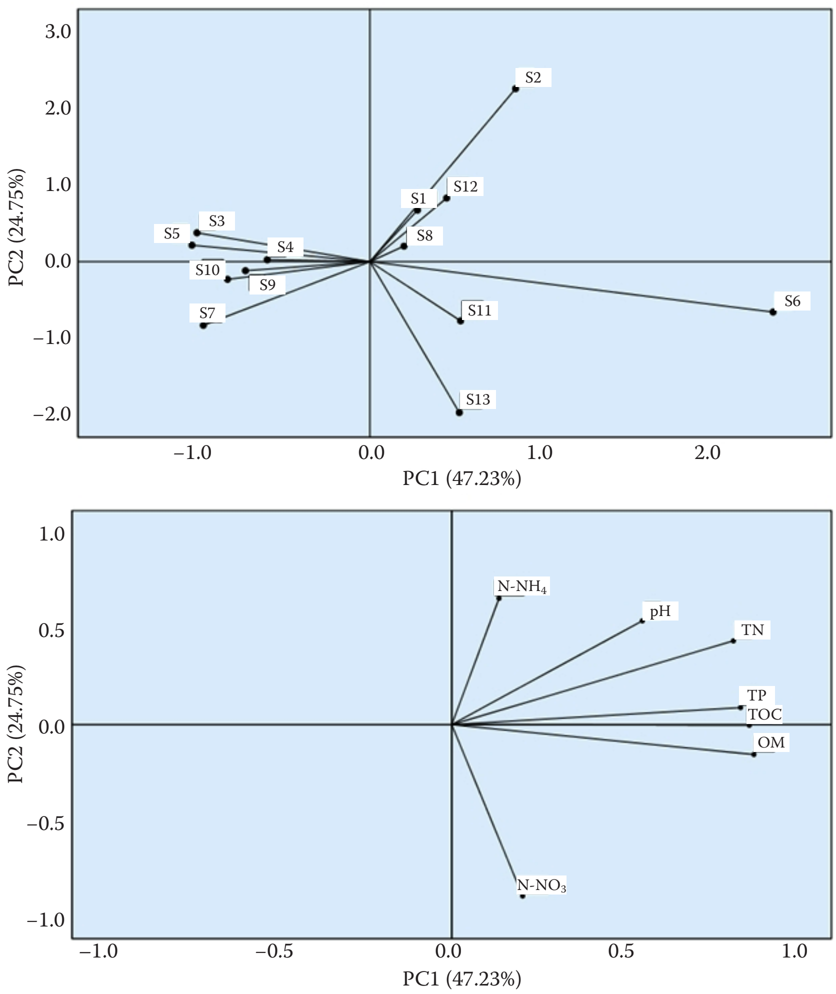

Figure 3. Principal component analysis (PCA) of the sampling stations and studied parameters in summer TP –total phosphorus; TN – total nitrogen; OM – organic matter; TOC – total organic carbon

summer (Figure 3). In the winter, the first principal component PC1 as factor 1 explained 46.16% of total variance and had a positive relation with ammonium, nitrate, PT, OM, and TOC. The second factor PC2 explained 31.81% of the total variance and was correlated with NT and pH. Three groups of sampling sites were identified in winter, the first group of stations located in the closed areas of Arekmane and Beninsar in addition to the center of the lagoon which are characterized by high depth and low hydrodynamics and have been subjected to anthropogenic pressure such as sewage discharge. The second group is represented by stations in the sandbar and near the coastline; it is marked by shallow depth and high hydrodynamics and influenced by the sea and the watershed.

During the summer, the first principal component PC1 as factor 1 explained 47.23% of total variance, and had a positive related with ammonium, nitrate, NT, PT, OM, and TOC. The second factor PC2 explained 24.75% of the total variance and was correlated with nitrate and ammonium.

In this season, also, three groups of sampling stations were identified; the first group was characterized by the station located in the lagoon centre, the second group was represented by the stations in the old eutrophic areas of Arekmen and Beniensar in addition to the station near the sewage treatment plant of Nador, this group of stations is marked by anthropogenic pressure in the past and currently. The third group is represented by the stations located in the mouths of Wadis influenced by the watershed, and the sampling sites near the new inlet with marine influence, and significant hydrodynamics.

Organic index. In the current study, the OI in the Marchica lagoon ranged from 0.0028–0.766, with average value of 0.246 in winter. In summer, the OI varied between 0.0045–0.516, with average value of 0.126. These findings indicate an uncontaminated to heavily contaminated level of organic risk in the lagoon, based on their respective thresholds illustrated in Figures 4 and 5.

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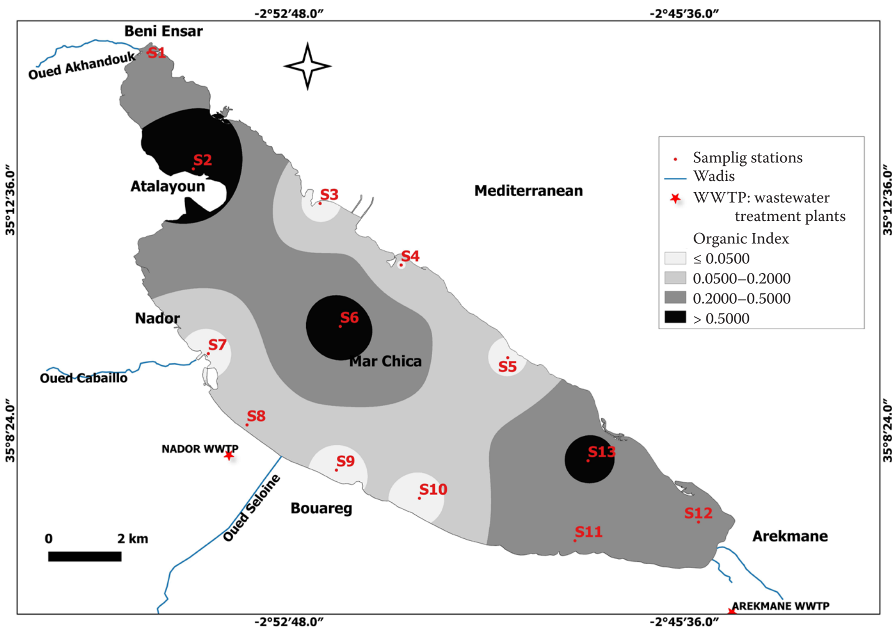

Figure 4. Spatial variation of organic index (C, N) during winter

Correlation of organic matter, TOC, TN and TP with sediment granulometry and geochemistry. Spearman's correlation coefficient matrix of the granulometry and geochemical contents, and nitrogen and TOC and TP in the surface sediment (Table 3) showed that the TOC was associated with silt and clay particles, this is in agreement with results of Aknaf et al. (2022) but no correlation showed between grain size content and OM.

These findings are in accordance with Pérez-Domingo et al. (2008) for the Gulf of Gabes, and Khedhri et al. (2016) for the Boghrara Lagoon; and these authors indicated an absence of correlation between sediment granulometry and organic matter content. Other authors (Ayari & Afli 2008) for the small Gulf of Tunis, noted the presence of correlation. The absence of correlation might be explained by currentology and hydrodynamics, but also by the battymetrie of the lagoon, therefore, organic fractions and mineral fractions don't have the same patterns of sedimentation and deposition. In the same context, it should be pointed out that the dynamic

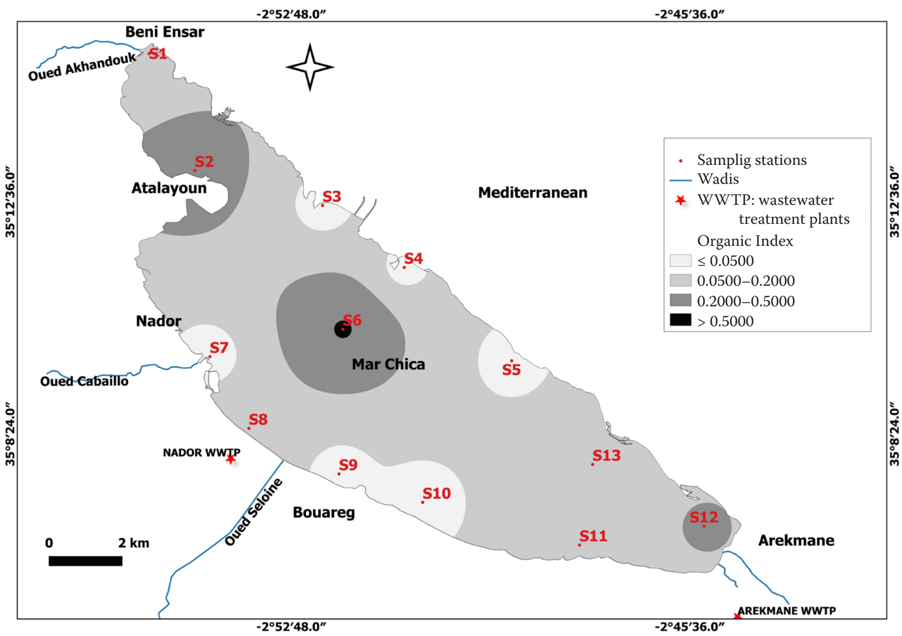

Figure 5. Spatial variation of organic index (C, N) during summer

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Table 3. Spearman's correlation between organic matter (OM), total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), geochemistry and granulometry

	$N\text{-}NO_3$	$N\text{-}NH_4$	pH	TP	TN	Sand	Clay + silt	OM	TOC	Al	Fe	Mn	Ca
$N\text{-}NO_3$	1												
$N\text{-}NH_4$	0.462*	1											
pH	−0.325	−0.282	1										
TP	−0.074	0.22	−0.15	1									
TN	−0.205	0.173	−0.189	0.705**	1								
Sand	0.152	−0.084	−0.387	−0.292	−0.356	1							
Clay + silt	−0.152	0.086	0.385	0.291	0.358	−1.000**	1						
OM	0.357	0.567**	−0.269	0.608**	0.555**	−0.302	0.305	1					
TOC	0.052	0.414*	−0.019	0.576**	0.699**	−0.478*	0.479*	0.837**	1				
Al	−0.014	0.187	−0.069	0.651**	0.440*	−0.439*	0.438*	0.424*	0.32	1			
Fe	0.115	0.246	−0.087	0.645**	0.361	−0.400*	0.399*	0.463*	0.334	0.951**	1		
Mn	−0.026	−0.098	−0.066	0.376	0.094	0.188	−0.19	0.125	0.04	0.536**	0.633**	1	
Ca	−0.138	−0.31	0.146	−0.610**	−0.410*	0.409*	−0.409*	−0.559**	−0.357	−0.943**	−0.938**	−0.466*	1

*, **Correlation is significant at the 0.05 and 0.01 level (2-tailed)

equilibrium (suspension vs. sedimentation) of sedimentary and suspended organic matter is regarded as one of the principal factors influencing their spatial distribution (Pusceddu et al. 1999). Our finding also showed positive correlation between TP and TOC and TN and geochemical content of sediment and showed negative correlation with Ca. Certain authors (Zaaboub et al. 2014) indicated that **s**ediments are an excellent immobilizer for phosphorus, which is mostly precipitated as Ca-P, Fe-P, and org-P in oxic circumstances (winter), but in anoxic settings (summer), dissolution of Fe-P, org-P, and Ca-P at low clay level in the sediment can be seen. Coelho et al. (2004) reported that phosphorus bound to Al, Ca, Fe, and Mn, the calcium bound P fraction increased with increasing marine influence, the organic P content decreased with depth, due to continuous mineralisation in the deeper sediment layers and vegetation. Furthermore, there is a strong positive correlation between TN and TP and TOC and Fine fractions in relation to their high proportions in organic form (Ben Mna et al. 2021).

CONCLUSION

In this study, the organic index of bottom sediments has been generally higher in old eutrophic and closed areas, highlighting the potential role of sediments in the retention of organic matter (C, N and P). The average concentrations of OM, TOC, TN and TP in the sediment samples of the Marchica Lagoon showed high concentrations, especially in the old-eutrophic areas. Our results clearly show that the restoration activities (the opening of the new inlet with the Mediterranean Sea, solid waste management, and sewage treatment plants) have resulted in a considerable reduction of organic pollutants in the lagoon sediments. However, these sediments still act as a reservoir or sink for pollutants such as organic pollution. Moreover, the organic index showed that the bottom sediments are classified into groups with no contamination and other heavily contaminated groups. Land-based sources of pollution must be controlled because they also feed the bottom sediments. Furthermore, lagoon restoration will take decades, with or without external nutrient inputs, and will remain in their current state if bottom sediments are left without restoration actions. The sediments should be used as a tool for systematic assessment and management, and to ensure environmental protection and the conservation of the ecosystem of this important wetland.

https://doi.org/10.17221/142/2022-SWR

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Received: October 23, 2022
Accepted: June 28, 2023
Publish online: July 20, 2023