Application of eutrophication indices for assessment of the ecological quality of the Moroccan eastern Mediterranean coast: Ras Kabdana-Saïdia

Hamza Ngadi[1*], *Mostafa* Layachi[2], *Ghizlane* Azizi[1], *Chaouki* Belbachir[3], *Sara* Esseffar[1], *Yassine* El Yousfi[4], *Hicham* Gueddari[1], *Abderrahmane* Rahhou[1], *Hamza* Loukili[1] and *Abdelmajid* Moumen[1]

[1]OLMAN- RL, Faculté Pluridisciplinaire de Nador (FPN), Université Mohammed 1er, B.P: 300, Selouane, 62700, Nador, Morocco

[2]Centre Régional de l'INRH-Nador-, 13 Boulevard Zerktouni BP: 493, Nador, Morocco

[3] Laboratoire Régional de Recherche et d'Analyse de Berkane – ONSSA, Qualipole Alimentaire, Agropole de Berkane, Berkane, Morocco

[4] Environmental Management and Civil Engineering Team, ENSAH, Abdelmalek Essaadi University, Tetouan 93030, Morocco

Abstract. Eutrophication of littoral seawater is estimated to be one of the main threats to marine biota. Therefore, continuous monitoring is necessary to define areas of potential risk. Our work is an essay to explore the possibility of applying the trophic state index (TRIX) to assess the state of eutrophication along the eastern coast of the Moroccan Mediterranean (Ras Kabdana-Saïdia) in concert with a number of hydro chemical parameters and nutrients descriptors aimed at selection of relevant indicators of marine coastal area ecological quality. Seawater samples were studied monthly during 2018. The following environmental parameters have been considered: temperature, salinity, pH, suspended matter, turbidity, dissolved oxygen, saturation levels, nitrite, nitrate, and orthophosphate. Principal Component Analysis was applied in order to figure out and score the most relevant combination of parameters to discriminate between sites and select representative descriptors (pressure/state) of eutrophication. The following variables are defined as relevant descriptors for classification of the sites: nutrients (N, P) and their molar ratios (N/P), the capacity of the system to produce and sustain organic matter (chlorophyll a), and the trophic state index (TRIX). The results show TRIX values below 4, the eutrophication range indicated that there is no ecological risk. The Ras Kabdana-Saïdia is located in an oligotrophic state.

1 Introduction

The Moroccan marine environment is threatened by several types of pollution [1-5]. Indeed, the coastal area of Ras Kabdana-Saïdia has experienced unprecedented urban, tourists and agricultural development, and the coastal waters have served as a place of discharge for almost all activities related to this development. Nutrient contaminants (nitrate, nitrite phosphate and silicate), are part of these discharges, have adverse effects on human health and marine ecosystems [6-8]. However, human activities can lead to an increase in nutrient concentration in ecosystems; a phenomenon known as eutrophication [6, 9]. Signs of eutrophication in marine waters show an increase in primary product levels to an abnormal level. This results in a significant increase in the growth of vascular plants, the appearance of a blooming phenomenon,

* Corresponding author email: ngadih.environnement@gmail.com

and a severe decrease in the concentration of dissolved oxygen in aquatic systems, which affects the aquatic environment [10].

Seawater quality assessment is a major concern, along with safety and accessibility, worldwide. Water contaminated with excessive chemicals poses a high health risk [11-13]. In recent times, high levels of contaminants and wastes worldwide are being released into the marine environment. This increases human exposure to many harmful environmental problems. Economic impacts on fishing and tourism have been linked to the degree of deterioration of environmental conditions [14]. The water quality index is a key indicator for assessing the pollution status of marine waters [15].

Water quality monitoring is an essential strategy for determining chemical, physical, and biological characteristics that allow early detection of potential pollution sources, and water quality information is very important to support planning and management of coastal and marine areas under the influence of human activities [1, 5, 16, 17]. Ecological indicators are commonly used to provide information on the status of ecosystems [5, 18]. Environmental indicators can be used for coastal eutrophication assessment because they capture and simplify complex environmental conditions in water and offer information that is easily understood by stakeholders and decision makers [19].

The most frequently used variables to describe eutrophication processes in estuaries are dissolved inorganic nutrients (nitrate, nitrite, ammonium, orthophosphate), algal biomass (Chl *a*), and water transparency [20]. Several classification criteria have been developed to assess the trophic status of coastal ecosystems using unimetric and multimetric indices based on arithmetic combinations of these environmental factors [21]. Unimetric indices consider variables used in water quality monitoring by means of algorithms [22] or in reference to an established trophic level [23].

However, for a better approximation of the assessment of temporal and spatial variation in trophic status, it is recommended to use multi-metric indices that consider nutrient enrichment, biomass production and oxygen content as variables reflecting the main causes and effects of eutrophication [24]. Different indices (Trophic Status Index: TSI and TRIX Trophic Index) have been used to assess trophic status on transitional systems coastal lagoons [25], estuarine and marine-coastal areas [26] in Europe [27], North America [28]. The Trophic Index (TRIX) functions as a multivariate tool, encompassing four variables, which are highly correlated with primary production: chlorophyll *a*, total nitrogen (TN), total phosphorus (TP) and oxygen saturation.

The TRIX index was initially developed for Italian coastal waters, but later it was applied in other regions, coastal areas of Montenegro [29], Red Sea [8], Lake Mariout [30], the Adriatic Sea [31], Izmir Bay [32] and the Mediterranean Sea [33].

The main objectives of this study are to monitor and evaluate the physical and chemical characteristics as well as the trace element contamination and eutrophication status of the seawater along the Moroccan Mediterranean coast (Ras Kabdana-Saïdia). The present study provides a scientific basis of data that would contribute to maintain the security of the ecosystem and promote the ecological economy.

2 Material and methods

2.1 Study site

The study area is located in the extreme northeast of Morocco on the Mediterranean coast (Figure 1). Administratively, it is part of the Oriental Region and the provinces of Berkane and Nador and includes the urban commune of Saïdia and the rural communes of Madagh, Laâtamna and Ras Kebdana [34]. The natural setting is a vast flat coastal plain and low altitude (1 to 6 m above sea level), 5 km wide for 22 km long [35]. The presence of a salty water table and salty clay soils on the coastal plain makes it difficult to develop it for agricultural purposes [36, 37].

This continental plateau, rich in shellfish, receives the waters of the Oued Moulouya and has an important recreational activity during the summer period [38]. The coastal plain is characterized by low and irregular rainfall, with significant interannual and seasonal variations and a marked summer dry season. This variability explains the fluctuations of the water bodies, especially the surface water table, which outcrops when precipitation exceeds the seasonal average [39].

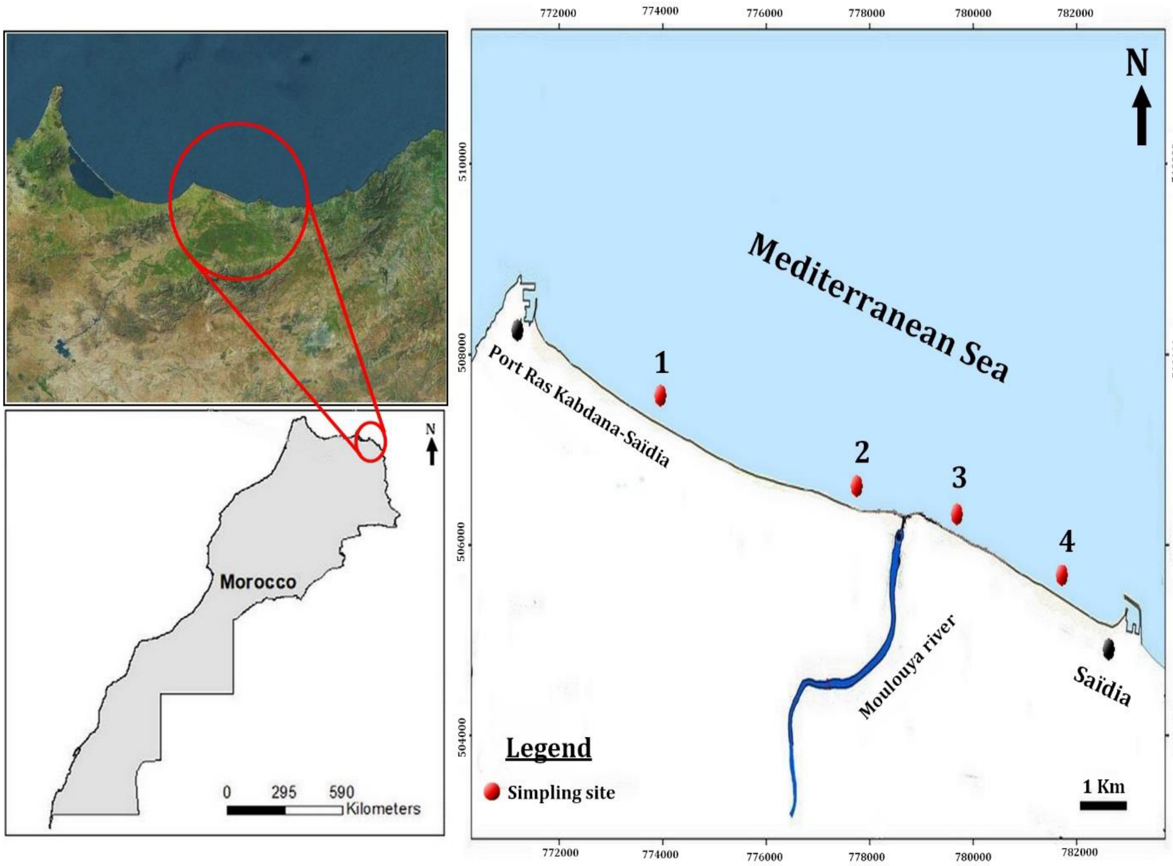

Fig. 1. Sampling location of the studied sites on the Ras Kabdana-Saïdia coastal area.

2.2 Water quality sampling

Hydro chemical characteristics: temperature (°C), pH, salinity (psu) and dissolved oxygen (mg/l) were measured *in situ* using a multi-parameter probe (type WTW), and the turbidity (NTU) was determined by a turbidimeter. The suspended smatter (SM) was determined from 1 L seawater samples by filtration through a washed, dried, and pre-weighed 0.45 μm membrane filter [4]. The filters with retained particles were washed, then air dried inside the oven at 60 ˚C for 24-48 hours to a constant weight. The difference between the dry weight of the membrane filters before and after filtration was expressed in mg/l determined according with standard AFNOR T90-105 [4;40]. Chlorophyll *a* (Chl *a*) was measured in water samples after collection and filtration through 0.45 μm filters. Chl *a* was extracted using 90% acetone and measured by spectrophotometer using the method given by Strickland and Parson [12].

Nutrient salts:

Nutrients were analyzed spectrophotometrically using a spectrophotometer. Nitrate (NO_3) and nitrite (NO_2) was determined according to DIN 38405-9, orthophosphate (PO_4^{3-}) was determined according to NM ISO 6878. Total phosphorus and total nitrogen were estimated in unfiltered seawater samples and determined according to the technique described by [41].

2.3 Assessment of eutrophication status

The following trophic index (TRIX) equation was used to assess the ecological risks of nitrogen and phosphorus [9, 42]:

$$TRIX = (\log 10 (Chl\ a * [\%\ DO] * DIN * DIP) + k)/m.$$

Here, Chl *a* = Chlorophyll-*a* concentration (µg/l), % DO = the oxygen percent saturation, DIN = dissolved inorganic nitrogen (µg/l), DIP = dissolved inorganic phosphorus (µg/l), K and m are constant where, k = 1.5 and m = 1.2. Based on the measurement of TN, TP, Chl *a* and transparency, classification of eutrophication status of Sea Waters of Ras Kabdana-Saïdia based on the terms of oligotrophic, mesotrophic, eutrophic, and hypertrophic.

Table 1. The TRIX index scale.

TRIX value	State water quality	Level of eutrophication	Trophic state
0<TRIX<4	high	low	oligotrophic
4<TRIX<5	good	medium	mesotrophic
5<TRIX<6	moderate	high	eutrophic
6<TRIX<10	poor and degraded	elevated	hypertrophic

2.4 Data analysis

The data were processed using SPSS IBM 25 software. To investigate the relationships between the variables and their possible distribution patterns, principal component analysis (PCA) was used. The PCA was applied to identify potential pollution and its characteristic elements. The effects of time on the hydro chemical and the nutrient salts of seawaters were analyzed using one-way analysis of variance (ANOVA) followed by Tukey's test. ANOVA data with a $P < 0.05$ was classified as statistically significant.

3 Results and discussion

3.1 Hydro chemical characteristics

Water temperature is one of the most important environmental parameters of an aquatic system. It is strongly influenced by the environmental conditions and by the geographical location of the different stations. The seawater temperature of Ras Kabdana-Saïdia (table 2) varies between a maximum value of 27.95 °C and a minimum value of 17.95 °C and therefore does not seem to pose a threat to the marine ecosystem. These results coincide with that observed by [43] in the Moroccan Mediterranean Sea, in which the temperature values were higher in warm periods and lower in cold periods. The average salinity value shown limited changes with an average of 35.84 psu. The changes in salinity were noticed due to the mixing of fresh and marine waters. The salinity of the coastal waters of Ras Kabdana-Saïdia can be affected mainly by freshwater runoff from the Moulouya River during rainy periods. The pH is a limiting factor in aquatic ecosystems: if the pH is lower than 4.5 or higher than 10, it becomes toxic for living organisms [44]. The pH of the water in the Ras Kabdana-Saïdia area remains within normal limits. On average, it was 8.15 and, was higher in winter than other seasons. Similar results were reported by [18] in the Moroccan Mediterranean Sea. The variation of dissolved oxygen level shows that the highest value was recorded in summer (9.71 mg/l), and the lowest value was found in winter (7.48 mg/l). These values are comparable to those of previous studies including [43] in the Moroccan Mediterranean Sea and [45] in the Aegean Sea in Turkey. Turbidity data confirm that the turbidity of seawater in the Ras Kandana-Saïdia littoral zone is higher during the rainy season (September to February) than during the dry period (March to August), with averages of 2.44 and 7.42 NTU for the dry and rainy periods, respectively. During the rainy season, turbidity reaches a maximum value of 11.15 NTU. The observed turbidity is due to leaching from the Moulouya river watershed. During the dry season, the maximum value of turbidity is 4.5 NTU, which is due to the tourist activity. This shows that the turbidity generated by rainfall is greater than that caused by tourist activity. Seasonal average suspended matter levels in the Ras Kabdana-Saïdia coastline fluctuate between 27.75 mg/l (spring) and 42.75 mg/l (winter). These results are similar to those found by [46] in the Moroccan Mediterranean Sea. However, this increase may be related to sediment resuspension due to periods of strong winds [2;47].

Chlorophyll *a* level in Ras Kabdana-Saïdia showed higher values in autumn (2.42 µg/l) and spring (1.51 µg/l), and lower in summer (0.4 µg/l) and winter (0.89 µg/l). The same results were found by [48] in the Beagle Channel mussel farm of Argentina. One of the principal pigments that can be used to gauge phytoplankton biomass is chlorophyll *a* [33]. In general, waters with high levels of nutrients from sewage treatment facilities, fertilizers, and urban runoff typically have high concentrations of Chl *a*.

Table 2. Min, max and average of the hydro chemical parameters in the coastal surface water of Ras Kabdana-Saïdia during 2018.

		T(°C)	Sal (psu)	pH	DO (mg/l)	Turb (NTU)	SM (mg/l)	Chl *a* (µg/l)
Spring	Mean	21.37[c]	36.25[b]	7.98[b]	8.17[c]	2.44[a]	27.75[a]	1.51[bc]
	Std. dev.	0.36	0.92	0.55	0.16	1.14	10.5	0.43
	Min.	21	35.7	7.88	7.85	1	13	1.1
	Max.	22.2	36.8	8.07	8.4	4.5	40	2.17
Summer	Mean	27.95[d]	36.67[b]	7.6[a]	9.71[b]	2.59[a]	35.5[b]	0.4[ab]
	Std. dev.	0.47	0.62	0.18	0.19	1	2.42	0.15
	Min.	27.3	36	7.36	7.45	1.29	31	0.24
	Max.	28.8	37.55	7.72	8	4	40	0.58
Autumn	Mean	17.95[a]	35.14[a]	8.51[c]	8.1[c]	6.71[b]	33[ab]	2.42[c]
	Std. dev.	0.7	0.11	0.08	0.07	1.82	2.41	1.76
	Min.	17	35	8.06	8	4.5	27	0.32
	Max.	19	35.6	8.9	8.5	8.95	37	4.21
Winter	Mean	18.57[b]	35.3[a]	8.61[c]	7.48[a]	7.42[b]	42.75[c]	0.89[a]
	Std. dev.	0.57	0.29	0.08	0.2	2.6	4.04	0.31
	Min.	17.85	34.7	8.3	7.1	4	36	0.43
	Max.	19.68	36	8.9	8	11.15	49	1.55
P-value		***	***	***	***	***	***	***

Std. dev.: standard deviation; Min: minimum; Max: maximum;T: temperature; Sal: salinity; DO: dissolved oxygen; Turb: turbidity; SM: suspended matter; Chl *a*: Chlorophyll *a*. Values in the same row marked with different letters (a, b, c and d) indicate significant differences (Tukey's test, $P < 0.05$), among seasons. ***: $P < 0.001$.

3.2 Nutrient salts

Nitrates are the final stage of nitrogen oxidation. Nitrate levels in the littoral zone of Ras Kabdana-Saïdia are low and evenly distributed over all sampling stations (table 3).

Table 3. Min, max and average of the nutrient salts in the coastal surface water of Ras Kabdana-Saïdia during 2018.

		NO_2 (µM)	**NO_3 (µM)**	**PO_4 (µM)**	**DIN (µM)**	**DIT (µM)**
Spring	Mean	0.26[a]	1.39[a]	0.21[b]	4.54[a]	0.67[b]
	Std. dev.	0.15	0.44	0.08	1.46	0.29
	Min.	0.09	0.58	0.1	1.91	0.3
	Max.	0.62	2.93	0.39	9.57	1.25
Summer	Mean	0.31[a]	2.02[b]	0.32[b]	7.35[a]	0.51[b]
	Std. dev.	0.1	0.7	0.13	2.55	0.23
	Min.	0.12	0.78	0.16	2.84	0.24
	Max.	0.5	3.28	0.85	11.91	1.45
Autumn	Mean	0.54[b]	3.57[c]	0.87[c]	6.14[b]	3.68[c]
	Std. dev.	0.04	0.29	0.21	0.5	0.86
	Min.	0.33	2.16	0.35	3.7	1.47
	Max.	0.71	4.68	1.7	8.03	6.97
Winter	Mean	0.49[ab]	2.27[b]	0.39[a]	9.26[ab]	1.45[a]
	Std. dev.	0.07	0.24	0.09	0.97	0.26
	Min.	0.33	1.35	0.11	5.53	0.46
	Max.	0.68	2.88	1.13	11.79	4.07
P-value		***	***	**	***	**

Std. Dev.: standard deviation; Min: minimum; Max: maximum; PO_4: orthophosphate; NO_3: nitrate, NO_2: nitrite.Values in the same row marked with different letters (a, b and c) indicate significant differences (Tukey's test, $P < 0.05$), among seasons. ***: $P < 0.001$; **: $P < 0.01$.

These levels are similar to those obtained by [14] in Cala Iris Bay, and [49] in the Italian Mediterranean Sea. However, they are much lower than the concentrations recorded by [50] in the Mediterranean coast of Turkey. The increase in nitrate and nitrite levels during the rainy season can be explained by drainage and leaching of agricultural soils in the Moulouya watershed where nitrogen fertilizers are used irrationally and resuspension of nitrates from sediments. The low levels of nitrates recorded may be related to the action of aquatic microflora likely to use them for the synthesis of new organic molecules. Orthophosphates are anions easily fixed by the soil. Their natural presence in water is linked to the characteristics of the soil and the decomposition of organic matter. Orthophosphate levels in the seawater of Ras Kabdana-Saïdia are higher than those found by [51] in the Moroccan Mediterranean Sea.

However, they are lower than the concentrations recorded by [52] in the Tunisian Mediterranean Sea. In the dry season, orthophosphates would mainly come from the intrusion of marine waters loaded with phosphate effluents discharged at sea. On the other hand, in the rainy season, they would be due to discharges from Oued Mouloya or by the leaching of agricultural land containing phosphate fertilizers or treated with phosphorus pesticides. In excess, nitrates participate in eutrophication phenomena with phosphorus.

3.3 Eutrophication state

The annual values of Chl *a*, % oxygen saturation, DIN and dissolved inorganic phosphorus was used to distinguish the status of eutrophication (TRIX) in the seawater of Ras Kabdana-Saïdia (table 4). The eutrophication of the seawater quality of the selected coastal area was evaluated.

The trophic index of the study period varied from 3.1 in summer and 4.36 in autumn. This increase can be explained by runoff from the Moulouya River and the agricultural area. Nutrient enrichment can be of natural origin, but it is often significantly increased by human activities, where the main sources of anthropogenic nutrient input are runoff, erosion and leaching from fertilized agricultural areas, urban wastewater and industrial wastewater [3;14;33]. The TRIX values showed that the Ras Kabdana-Saïdia is located in an oligotrophic state. In general, a low trophic index (TRIX < 4) was recorded in the study area (table 4) and the eutrophication range showed that there was no ecological risk based on the water quality status survey during 2018.

The TRIX water quality index is used in this study to express the water quality status for a wide range of element components especially nitrogen and phosphorus, if they are present in high concentrations from the surrounding areas. This index has been applied in many coastal marine areas in different regions of the world. There are many regions where this model has been applied, for example: the Adriatic Sea [22], the Black Sea [53], the Eastern Mediterranean Sea [54] and the Caspian Sea [55].

Dissolved inorganic nitrogen (DIN) and PO_4/P are the primary forms of N and P that are readily bioavailable for phytoplankton growth. Based on the data from this study, N/P ratios ranged from 1.66 in the fall to 14.41 in the summer periods. The average total N/P ratio was 7.3 which is lower than the optimal assimilative N/P=15/1 and N/P=16/1 ratio reported by [56]. According to previous studies [57], nitrogen and phosphorus are the limiting factors for seaweed growth. Phosphorus is the limiting factor for seaweed growth when the ratio of phosphorus to nitrogen is greater than six.

On the other hand, nitrogen is the limiting factor for growth when the ratio is below 4.5. In the range of 4.5 to 6, both nutrients are close to their optimal assimilation ratio. In the present study, the N/P ratio ranged from a low value (1.66) > 4.5 (N-limited) to very high value 14.41 (P-limited). Very high values of N/P ratios were recorded at most of the study periods, this consideration showed that phosphorus is a limiting factor in Ras Kabdana-Saïdia.

Table 4. Average of N/P ratios and Trophic State Index of the coastal surface water of Ras Kabdana-Saïdia during 2018.

	Spring	Summer	Autumn	Winter
N/P	6.77	14.41	1.66	6.38
TRIX	3.53	3.1	4.36	3.7

3.3 Statistical analysis

Figure 2 shows the principal component analysis of the physico-chemical parameters of Ras Kabdana-Saïdia with the first two axes (F1 and F2) illustrating 83.95% of the total variance or 58.81% and 25.14% of the inertia respectively.

The F1 axis is defined on the positive pole by turbidity and pH with strong relative contributions (CTR) of 0.92 and 0.89 respectively. This axis is defined on the

negative pole by salinity with CTR = 0.97 and temperature with CTR= 0.85.
On this axis are projected nitrite (CTR= 0.86), nitrate (CTR= 0.8) and orthophosphate (CTR= 0.79). The F2 axis is defined on the positive pole by dissolved oxygen (CTR = 0.94) and secondarily by chlorophyll *a* (CTR= 0.73).

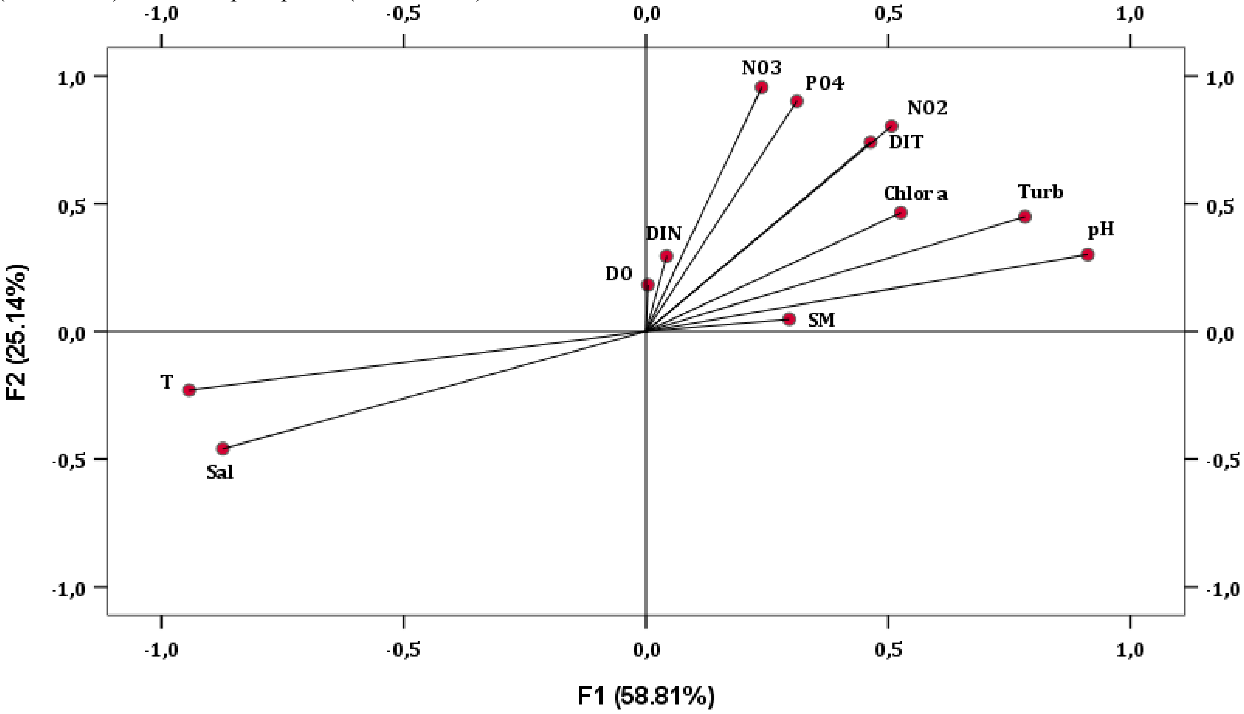

Fig. 2. Principal Component Analysis of the hydro chemical parameters and the nutrient salts in the coastal surface water of Ras Kabdana-Saïdia.

4 Conclusion

Our study used a trophic index to characterize and diagnose the trophic status and seawater quality of the Ras Kabdana-Saïdia coastline. Our results show that the values of the eutrophication index were relatively low, which allowed us to classify the coastal waters of Ras Kabdana-Saïdia as oligotrophic to mesotrophic. From the average value of N/P ratio, phosphorus is the limiting factor in the study area. In general, the seawater of Ras Kabdana-Saïdia does not present any risk of eutrophication during the study period. The environmental conditions in the study area identified by the application of these indices support their relevance to coastal zone monitoring and their applicability in understanding the environment. These indices can be used as tools to implement local public policies aimed at improving the basic sanitation of the population.

References

1 A, Moumen D.R. Yáñez-Ruiz, I, Martín-García, E. Molina-Alcaide, *J Anim Physiol Anim Nutr*. **92 (**2008).

2 H, Ait Hmeid, M. Akodad, M, Baghour, A, Moumen, A, Skalli, G. Azizi, *E3S Web of Conferences*, **234 (**2021).

3 H. Gueddari, M. Akodad, M. Baghour, A. Moumen, A. Skalli, Y. El Yousfi, A. Ismail, M. Chahban, G. Azizi, H. Ait Hmeid, M. Zahid *Sci. Afr.* **16 (**2022).

4 H. Ngadi, M. Layachi, G. Azizi, C. Belbachir, M. Baghour, A. Moumen, *Cah. Biol. Mar.* **62** (2021).

5 H. Ngadi, M. Layachi, C. Belbachir, G. Azizi, N. El Ouamari, M. Akodad, M. Baghour, A. Moumen, *J. Aquat. Biol. Fish.* **26** (2022).

6 K. Ben Chekroun, A. Moumen, N. Rezzoum, E. Sánchez, M. Baghour, *J. Exp. Bot.* **82 (**2013).

7 V. De Jonge, M. Elliott, E. Orive, *Hydrobiologia* **475 (**2002).

8 A. Bandar, *Saudi J. Biol. Sci.* **27 (**2020)

9 F. Chislock, E. Doster, R.A. Zitomer, E. Wilson, *Nat. Sci. Educ.* **4** (2013).

10 B. Bhagowati, K. Ahamad, *Ecohydrol. Hydrobiol.* **3 (**2018).

11 E. Molina-Alcaide, A. Moumen, I. Martín-García, D. Carro *J Anim Physiol Anim Nutr.* **93 (**2009).

12 G. Azizi, M. Layachi, M. Akodad, A.I. Martín-García, D.R. Yáñez-Ruiz, M. Baghour, H. Ait Hmeid, H. Gueddari, A. Moumen, *E3S Web of Conferences*, **240 (**2021).

13 G. Hicham, A. Mustapha, B. Mourad, M. Abdelmajid, S. Ali, E.Y. Yassine, A.H. Hanane, C. Mohamed, A. Ghizlane, R. Abderahmane, A. Ismail, M. Zahid *Environ. Qual. Manag.* **10 (**2021).

14 G. Azizi, Layachi M, Akodad M, Baghour M, Ghalit M, Gharibi E, Ngadi H, Moumen A 2020a *Ocean Sci. J.* **55**

15 E.V. Landau-Sabine, S.A. Brian, *Handbook of statistical analyses using SPSS* Chap man and Hall/CRC p. 366 (2003).

16 K. Dodds, H. Smith, *Inland Waters*, **6 (**2016).

17 G. Mahmoud, A. El-Khir, H. Ebeid, A. Mohamed, A. Fahmy, S. Shaban J. Environ. Prot. Sci. **11 (**2020).

18 G. Azizi, M. Layachi, M. Akodad, H. Ngadi, M. Baghour, A. Skalli, M. Ghalit, G. ELkhadir, A. Moumen *ACM International Conference Proceeding Series*, **6** (2020b).

19 R. Cervantes-Duarte, M. del Carmen Jimenez-Quiroz, R. Funes-Rodriguez, S. Hernandez-Trujillo, R. Gonzalez-Armas, E. Anaya-Godinez *Reg. Stud. Mar. Sci*. **42 (**2021).

20 V. Mourão, R. de Sousa, M. da Luz Mendes, M. Castro, C. da Silva, M. El-Robrini, S. Santos *Reg. Stud. Mar. Sci.* **39 (**2020).

21 D. Rohaningsih, A. Rahmadya *Earth Environ. Sci.* **33** (2022).

22 S. Sathishkumar, A. Sundaramanickam, K. Mohanty, G. Sahu, T. Ramesh, K. Balachandar, K. Silambarasan, *Oceanologia*, **64** (2022).

23 M. Iqbal, S. Hussain, M. Cheema, J. Lyul, *Pak. J. Agri. Sci.* **59 (**2022).

24 S. Gao, R. Zhang, H. Zhang, S. Zhang, *Environ. Pollut.* **297** (2022).

25 A. Specchiulli, S. Focardi, M. Renzi, T. Scirocco, L. Cilenti, P. Breber, S. Bastianoni, *Sci. Total Environ.* **402** (2008).

26 F. Giovanardi, A. Vollenweider, *J. Limnol.* **63 (**2004).

27 F. Salas, H. Teixeira, C. Marcos, C. Marques, A. Pérez-Ruzafa, *J. Mar. Sci.* **65** (2008).

28 R. Anguiano-Cuevasa, A. Olivos-Ortiz, O. Cervantes, I. Azuz-Adeath, N. Ramírez-Álvarez, C. Rivera-Rodríguez, *J. Integr. Coast. Zone Manag.* **15** (2015).

29 S. Krivokapić, B. Pestorić, M. Krivokapić *Stud Mar*. **29** (2016).

30 M. El Zokm, Z. Tadros, M. Okbah, G. Ibrahim, *Egypt. J. Aquat. Biol. Fish*. **22** (2018).

31 E. Fiori, M. Zavatarelli, N. Pinardi, C. Mazziotti, R. Ferrari, *Nat. Hazards Earth Syst. Sci.* **16** (2016).

32 F. Kucuksezgin, T. Gonul, I. Pazi, A. Kacar, *Reg. Stud. Mar. Sci.* **28** (2019).

33 A. Morsy, M. Ebeid, A. Soliman, A. Halim, E. Ali, M. Fahmy, *Environmental Challenges*, **7** (2022).

34 N. Bellahbib, H. Rezqui, M. Oujidi, S. Bengamra, *Larhyss J.* **24** (2015).

35 M. Layachi, Z. Bouthir, S. Benbrahim, A. Chiaar, R. Chfiri, F. El Madani, Y. Azzaoui, *J. Mater. Environ. Sci.* **5** (2014).

36 M. Mouzouri, Z. Irzi, *Bull. l'Institut Sci. Rabat Sect. Sci. la Terre*. **33** (2011).

37 C. Belbachir, A. Chafi, A. Aouniti, M. Khamri, *J. Mater. Environ. Sci.* **5** (2014).

38 T. Boumeaza, A. Sbai, M. Salmon, M. Benata, O. Andrée, *Mediterranean*, **115** (2010).

39 M. Mouzouri, Z. Irzi, A. Essaddek, *Rev. Fr. Photogramm. Teledetect.* **201** (2013).

40 A. Fahmy, A. Fattah, M. Abdel-Halim, A. Aly-Eldeen, M. Abo-El-Khair, H. Ahdy, A. Hemeilly, A. El-Soud, A Shreadah, *J. Environ. Prot. Sci.* 7(2016).

41 U. Hirt, J. Mahnkopf, M. Gadegast, L. Czudowski, U. Mischke, C. Heidecke, *Reg. Environ. Change*. **14** (2014).

42 A. Vollenweider, F. Giovanardi, G. Montanari, A Rinaldi *Environmetrics*. **9** (1998).

43 M. Bennani, H. Amarouch, A. Boukanjer, H. Nadre, M. Lalaoui, M. Allali, N. Cohen, *Eur. J. Res.***71** (2012).

44 E. Odjohou, M. Amani, G. Soro, S. Monde, *Int. j. biol. chem. sci.* **14** (2020).

45 M. Bilgin, E. Uluturhan-Suzer *Environ. Sci. Pollut. Res*. **24** (2017).

46 G. Azizi, M. Layachi, M. Akodad, D. Yáñez- R. Ruiz, I. Martín-García, M. Baghour, A. Mesfioui, A. Skalli, A. Moumen, *Mar. Pollut. Bull.* **137** (2018).

47 R. Koffi-Nevry, P. Manizan, A. Wognin, M. Koussemon, S. Koffi, T. Kablan, C. Kakou, *Eur. J. Res*. **21** (2008).

48 E. Giarratano, A. Amin, *Ecotoxicol. Environ. Saf.* **73** (2010).

49 S. Lamon, G. Consolati, F. Fois, G. Cambula, M. Pes, G. Porcheddu, D. Meloni *J. Food Prot*. **82** (2019).

50 M. Belivermiş, O. Kılıç, Y. Çotuk *Chemosphere*, **144** (2016).

51 H. Mannas, R. Mimouni, N. Chaouqy, F. Hamadi, J. Martinez-Urtaza Springerplus, **3** (2014).

52 M. Abidi, B. Amor, M. Gueddari, *J. Chem*. **16** (2018).

53 A. Alkan, S. Serdar, D. Fidan, U. Akbaş, B. Zengin, B. Kiliç, *Chemosphere*, **302** (2022).

54 N. Bada, Z. Da Ros, F. Rindi, S. Busi, E. Azzurro, F. Derbal, E. Fanelli *Mar. Environ. Res*. **173** (2022).

55 S. Tugrul, Z. Uysal, E. Erdogan, N. Yucel, *Ekoloji*, **20** (2011).

56 C. Redfield, H. Ketchum, A. Richards *The influence oforganisms on the composition of seawater In the Sea* (New York: Wiley–Interscience) (1963).

57 G. Chiaudani, M. Vighi, *Quad. Instituto di RicercaSulleAcque (IRSA)* **39** (1978).