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Integrating diatom indices and organic pollution metrics for ecological diagnosis of urban wadis in Greater Casablanca (Morocco)

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ABSTRACT

Population growth combined with intensified agro-industrial activity in the Greater Casablanca region has increased pollutant inputs into adjacent aquatic systems, requiring robust ecological assessment tools. This study evaluates, for the first time, the ecological quality of five wadis in this region using benthic diatoms as bioindicators integrated with physicochemical parameters and an organic pollution index. Eleven stations distributed along an upstream–downstream gradient (Nfifikh, El Maleh, Hassar, Bouskoura, and Merzeg wadis) were surveyed during wet and dry seasons of 2024. Ecological status was assessed using the generic diatom index (IDG), specific polluosensitivity index (IPS), and diatom saprobic and eutrophication index (IDSE), and compared with the organic pollution index (IPO). Community structure was analyzed through taxonomic composition and multivariate analysis. Numerical results show strong spatial differentiation of ecological conditions. One station (EM1) exhibits oligo-mesotrophic conditions with good to moderate ecological status (IDG up to 13.01; IPS up to 13.12; IDSE up to 3.6), whereas B1 reflects intermediate degradation with mesotrophic to eutrophic conditions (IDG 9.02–10.17; IPS 8.45–9.17). The remaining stations (N2, EM2, H1–H2, B2, M1–M2) consistently fall into poor to very poor ecological classes, with hypereutrophic conditions and dominant pollution-tolerant taxa, particularly *Nitzschia* spp. Correlations between diatom indices and IPO are highly significant ($p < 0.01$). Notably, 14 taxa are newly reported for Moroccan freshwater ecosystems. The study is limited by incomplete seasonal accessibility of certain stations, which may reduce temporal resolution of community dynamics. Nevertheless, the results provide a coherent ecological diagnosis across heterogeneous hydrosystems. Practically, the findings support the use of diatom-based indices as integrative tools for monitoring cumulative pollution impacts and distinguishing eutrophication from organic loading. The originality of the study lies in the first basin-wide diatom assessment of Greater Casablanca wadis combined with multi-index comparison and first records of regional taxa. This establishes a baseline for future ecological monitoring and comparative studies in North African semi-arid river systems.

Keywords: bioindicators, diatoms, ecological indices, eutrophication, organic pollution, water quality.

INTRODUCTION

The accelerated degradation of aquatic ecosystems, particularly that of rivers, is a major environmental challenge on a global scale. This problem is particularly worrying in arid and semi-arid regions, of which Morocco is a representative example. These disturbances are closely linked to the intensification of anthropogenic pressures on water resources, where socio-economic requirements, including intensive agriculture, urbanization, and industrialization, often exceed the resilience capacities of aquatic environments. The Greater Casablanca region clearly illustrates this situation of environmental vulnerability (El Morabet et al., 2024; Guellaf and Kettani, 2025).

The accumulation of organic matter can trigger a process of eutrophication, characterized by phytoplankton blooms. These blooms significantly alter aquatic ecosystems, generating health risks through hypoxia or the production of toxins (Dedjiho et al., 2013).

The condition of aquatic ecosystems is generally determined through an examination of physical and chemical variables, the organic pollution index (IPO), and bacteriological parameters, supplemented by the study of the bioindicator organisms, specifically the resident biological communities, like invertebrate fauna and periphytic algae, chief among them the diatom group (Bacillariophyceae) (Haidar et al., 2025). The latter react rapidly to changes in environmental conditions and are strongly influenced by the physicochemical composition of the water, encompassing temperature, pH, organic matter load, and nutrient concentrations, mainly nitrogen and phosphorus (Bona et al., 2024). Due to their ecological sensitivity and wide distribution, they are particularly reliable bioindicators for the biological and environmental assessment of water quality.

Since the 2000s, the gradual integration of many diatom indices into the Omnidia software has significantly improved the ecological assessment of aquatic ecosystems on an international scale (Bytyçi et al., 2019). In this study, three complementary indices were used, namely The Generic Diatom Index (IDG) (Coste and Ayphassorho, 1991) for an overall assessment of ecological integrity, the specific polluosensitivity index (IPS) (Cemagref, 1982) assessing the sensitivity to organic pollution and the diatom saprobic and eutrophication index (IDSE) of Leclercq and Rosengarten (2008) characterizing trophic and saprobic processes.

The main objective of this study is to provide the first comprehensive ecological assessment of the wadis of Greater Casablanca using diatom-based bioindication, integrating spatial and seasonal variability across eleven sampling stations distributed along five hydrosystems (Nfifikh, El Maleh, Hassar, Bouskoura, and Merzeg). This approach aims to establish a baseline framework for ecological quality assessment in highly anthropized Atlantic Moroccan river systems.

This study is based on the following hypotheses:

- H1: Spatial variation along upstream–downstream gradients significantly structures diatom community composition, reflecting increasing anthropogenic pressure downstream.
- H2: The temporal variation between the wet and dry periods implies a deterioration in the indices and water quality during the dry period.
- H3: Diatom-based indices (IDG, IPS, IDSE) are significantly correlated with physicochemical indicators and the Organic Pollution Index (IPO), confirming their reliability as bioindicators in Mediterranean semi-arid river systems.
- H4: Stations exposed to higher nutrient and organic loads are characterized by reduced diatom diversity and dominance of pollution-tolerant taxa (e.g., *Nitzschia* spp., *Navicula* spp.), whereas less impacted stations maintain more balanced and taxonomically diverse assemblages.
- H5: The combined use of multiple diatom indices provides a more robust and ecologically discriminative assessment of water quality than any single index alone.

MATERIALS AND METHODS

Description of the Greater Casablanca study area

In the heart of the Moroccan Atlantic coast (33° 35’ 17’’ N, -7° 36’ 40’’ W), the Greater Casablanca region includes the prefectures of Mohammedia and Casablanca, as well as the provinces of Médiouna and Nouaceur. The largest metropolis in Morocco, it stretches over 50 km of coastline, forming a conurbation from El Jadida to Kenitra (Troin, 2011). The economic and industrial capital is home to 5.02 million inhabitants (HCP, 2024) over 1.615 km². Its location in the fertile plain of the Chaouia in Morocco (Asslouj et al., 2007) makes it also a major agro-industrial center. Located in the coastal Meseta, Greater Casablanca rests on a Cambro-Ordovician basement (schists, sandstones, quartzites), capped by Meso-Cenozoic deposits. The Mesozoic begins in the Triassic (siltstones, sandstones, conglomerates, then lower argillites), followed by upper argillites of the Lias. The Cenozoic is characterized by Plio-Quaternary limestones. (Belkhattab and Ghalem, 2010).

Located on the Atlantic coast, Greater Casablanca has a semi-arid climate under the influence of the ocean: dry and hot summers, mild, wet, and rainy winters. (General monography, 2015; Sebbar et al., 2012). With an average annual temperature of 17.8 °C and rainfall of around 430 mm per year, Greater Casablanca experiences its peak heat in August (23.3 °C on average) and its coolest period in January (Hassani et al., 2021).

Sampling sites

Five wadis of the Greater Casablanca region and eleven sampling stations were selected based on exposure to anthropogenic pressures (industrial, agricultural, domestic, and wastewater discharges) (Table 1), accessibility, hydrological location, and the availability of historical data on water physicochemistry, as these are the sampling stations of the Bouregreg de la Chaouia River Basin Agency (ABHBC). The sampling design corresponds to a targeted approach aimed at capturing pollution gradients along urban–peri-urban watercourses.

Sampling campaigns were conducted during two hydrological periods: winter (February–March) and summer (July–August) 2024. All stations were sampled in both seasons, with a total of one sample per station per season, with the exception of station H1, which was dry during the summer period. Independent samples per station per campaign to ensure temporal comparability. Stations included upstream and downstream locations along several wadis in order to capture longitudinal pollution gradients (Figure 1). Hydrological independence between stations was assumed based on spatial separation; however, the pollution observed in the wadis does not exclude any potential for upstream–downstream autocorrelation.

The selection of sampling points along each wadi was based on visible pollution sources and land-use pressure; furthermore, historical data on the physicochemical quality of the water confirm systematic pollution in the region.

This sampling structure was designed to allow comparison of spatial and seasonal variability in physicochemical parameters and diatom assemblages under differing anthropogenic pressure regimes.

Physicochemical analyses

The sampling used polyethylene bottles (250–500 ml), with refrigerated transport at 4 °C in a cooler to the laboratory. The physicochemical analyses focused on ten key parameters: temperature (T), pH, suspended solids (TSS), electrical conductivity (EC), dissolved oxygen (O_2), sulphates (SO_4^{2-}), biochemical oxygen demand (BOD_5), ammonium (NH_4^+), nitrates (NO_3^-), and orthophosphates (PO_4^{3-}).

Measurements of T, pH, EC, and O_2 were performed in situ using a WTW pH meter, a WTW conductivity meter, and an HQ30d HACH oximeter, respectively. Chemical analyses, in particular BOD_5 (NF EN 1899.1), NH_4^+ (NF T 90-015.1), NO_3^- (NM ISO 7890-3), PO_4^{3-} (NF EN ISO 6878), SO_4^{2-} (NF T 90-040) and SS (NF EN 872), were quantified in the laboratory within 24 hours of sampling, in accordance with the AFNOR and IMANR standards in force referenced above.

Table 1. Characteristics of the study stations with Lambert coordinates

Station	Commune	Wadis	Name of sampling stations	Lambert coordinates		Type of pollution
				X	Y	
N1	Mohammedia	Nfifikh	Following the discharge point	325220	340210	Discharge
N2	Mohammedia		Close to the outlet (Downstream)	320092	348024	Wastewater
EM1	Fedalat	El Maleh	Dam (Upstream)	319711	324847	Reference station
EM2	Sidi Moussa Majdoub		El Maleh (Midfielder)	314043	338351	Agricultural pollution and wastewater
EM3	Mohammedia		Wetland (downstream)	313337	344413	
H1	Sidi Hajjaj	Hassar	Sidi Hajjaj (Upstream)	312150	328425	Wastewater + discharge from the Médiouna WWTP
H2			Dam (Downstream)	311402	332449	
B1	Bouskoura	Bouskoura	Source (Upstream)	291150	318980	Wastewater
B2			Sidi Ayad (Downstream)	288850	325350	Agricultural pollution
M1	Sahel Ouled H'riz	Merzeg	Merzeg (Upstream)	278960	310752	Domestic and Industrial pollution
M2	Ouled Azouz		Merzeg (Downstream)	278765	321562	

Note: WWTP – wastewater treatment plant.

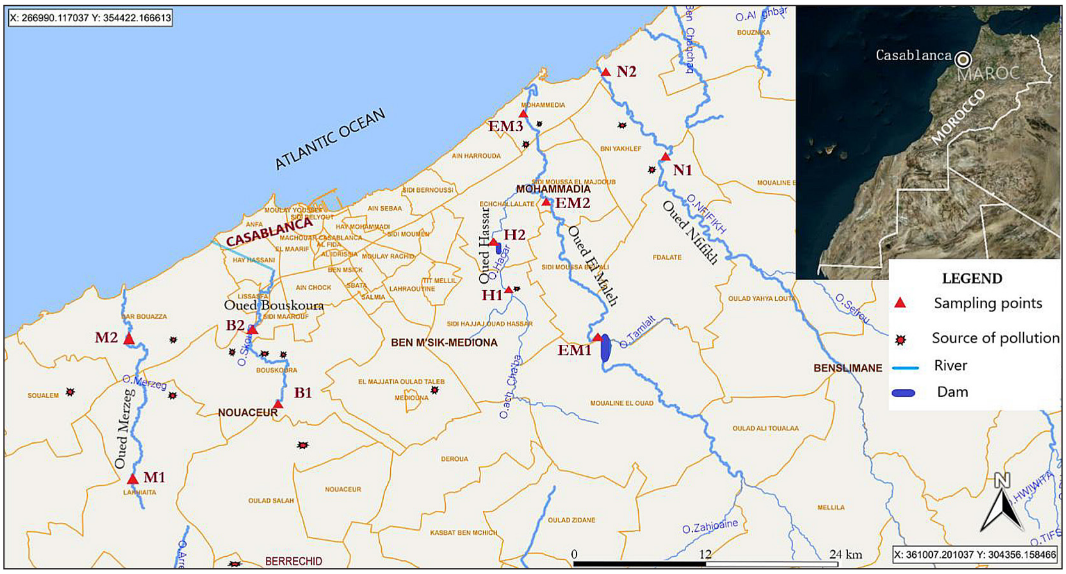

Figure 1. Location of study stations on a map of Greater Casablanca

Organic pollution index (IPO) – the organic load was assessed using the organic pollution index (IPO) proposed by Leclercq and Maquet (1987). This index incorporates four indicators: ammonium (NH_4^+), biochemical oxygen demand (BOD_5), nitrites (NO_2^-), and orthophosphates (PO_4^{3-}). Each parameter is classified according to a reference pollution scale (Table 2. A.), according to the methodology of Leclercq and Vandevenne (1987). The final value of the IPO corresponds to the average of the classes assigned, thus providing an integrated synthesis of the organic pollution at each site. It is a tool whose scientific relevance for North African aquatic environments has been validated, and its reliability as an indicator for the assessment of the chemical quality of rivers in Morocco has been demonstrated (Bekri et al., 2020; Hachi et al., 2022).

Sampling, processing, and identification of diatoms

Five natural substrates per station were collected and scraped with a toothbrush to collect benthic diatom biofilms, in accordance with NF EN 13946 (2003). The sampling effort per substrate was standardized by scraping an area of 15 to 25 cm² per substrate, ensuring comparable quantitative coverage across stations.

Immediately after collection, samples were transported to the laboratory under cooled conditions (4 °C). The samples were preserved using 10% Lugol and stored for a maximum of 15 to 18 h prior to analysis.

Organic matter removal was performed using hydrogen peroxide (H_2O_2 40%) and hydrochloric acid according to NF T90-354 (2016), following Marezza et al. (2021). At a rate of 4 ml of the sample to 20 ml of H_2O_2 in a glass test tube. Chemical digestion was carried out for a period of 2 to 4 h, depending on the raw state of the sample, at controlled temperatures of 100 to 150 °C in a sand bath, followed by 3 rinses at 2000 rpm during 5 minutes of centrifugation to obtain clean frustule suspensions.

Microscopic observations were conducted using a light microscope at 40–100× magnification. Taxonomic identification was performed using standard keys (Rumeau and Coste, 1988; Prygiel and Coste, 2000; Lavoie et al., 2008), algaebase.org, and Diatoms.org (Spaulding et al., 2021).

Taxonomic determinations were based on mixed resolution, which was applied consistently across all indices (genus-level for IDG and species-level for IPS and IDSE), and identification quality was ensured by a double-check procedure.

For diatom index calculations, a minimum of 400 individuals per sample was counted. Counts were performed on full permanent slides, and each sample was processed in independent counting sessions to ensure statistical reliability.

Determination of ecological status with IDG, IPS, and IDSE

To determine the ecological status and level of alteration of watercourses, three indices integrated into the Omnidia software (Lecointe et al., 2003) were used, namely: the generic diatom index (IDG) (Coste and Ayphassorho, 1991), the specific polluosensitivity index (IPS) (Cemagref, 1982), cited by Bytyçi et al. (2019), and the diatom saprobic and eutrophication index (IDSE) of Leclercq and Rosengarten (2008) quoted by Singh et al. (2018).

The ecological status and trophic status of the rivers were determined using three biotic indices derived from diatom assemblages, which are different in sensitivity to different types of pollution (Bytyçi et al., 2019), as detailed in Table 2. B.

The determination of pollution sensitivity changes depending on the diatom index used. It is carried out at the genus level for the IDG, but requires a more detailed identification, up to the species level, for the calculation of the IPS and the IDSE.

The level of trophic weathering is determined by the IDSE while distinguishing the cause from the weathering, as shown in Table 2. B. The IDSE gives similar scores to the IPS, but its major advantage is that it provides additional information by separating the impact of pollution by anthropogenic eutrophication (AE) and organic pollution (OP). This precision is crucial for a better interpretation of the quality of the water and the origin of the pollution. According to data from the Omnidia software, the sensitivity groups are divided into five bioindicator groups, with a value of 1 for the most resistant taxa and 5 for the most sensitive taxa. Therefore, the relative abundance of the different taxa, divided into these five groups, makes it possible to quantify two types of major disturbances, namely anthropogenic disturbance and organic disturbance (Leclercq and Rosengarten, 2008) :

- Organic pollution (OP): assessed by the sum of the abundances of groups 2 and 1, corresponding to resistant and very resistant taxa to organic matter;
- Anthropogenic eutrophication (AE): measured by the abundance of group 3, which includes taxa favored by nutrient enrichment (in particular nitrates and phosphates).

Determination of the species diversity and equitability of diatom genus assemblages

The diversity (H’) of diatom genus assemblages was determined in the samples as defined by the Shannon-Weaver diversity index (1963) (Azonningbo et al., 2021), which measures the heterogeneity of a sample according to the formula from Equation 1:

Table 2. Benchmark thresholds for organic pollution and diatom-based metrics

A: Organic Pollution Index and degrees of organic pollution according to Bekri et al. (2020)

Classes	NH_4^+ (mg/l)	BOD_5 (mg/l)	NO_2^- (µg/l)	PO_4^{3-} (µg/l)	IPO	Organic pollution
5	< 0.1	< 2	≤ 5	≤ 15	4.6–5.0	Null
4	0.1–0.9	2.1–5	6–10	16–75	4.0–4.5	Low
3	1–2.4	5.1–10	11–50	76–250	3.0–3.9	Moderate
2	2.5–6	10.1–15	51–150	251–900	2.0–2.9	Heavy
1	>6	>15	> 150	> 900	1.0–1.9	Very heavy

B: Diatom indices, trophic statuses with ecological status, and levels of degradation of the IDSE as reported by Bytyçi et al. (2019) and Singh et al. (2018)

Classes	IDG & IPS	IDSE	AE & OP	Trophic status	Ecological status
I	17–20	4.3–5.0	< 10%	Oligotrophic	Very good
II	13–16	3.6–4.2	10–20%	Oligo-Mesotrophic	Good
III	9–12	3.0–3.5	20.1–45%	Mesotrophic	Moderate
IV	5–8	2.3–2.9	45.1–70%	Eutrophic	Poor
V	1–4	1.0–2.2	> 70%	Hypertrophic	Bad

Note. NH_4^+: ammonium, BOD_5: biochemical oxygen demand over 5 days, NO_2^-: nitrite, PO_4^{3-}: orthophosphates, IPO: organic pollution index; IDG: generic diatom index; IPS: specific polluosensitivity index; IDSE: diatom saprobic and eutrophication index; AE: anthropogenic eutrophication; OP: organic pollution.

$$H' = -\sum_{i=1}^{S} Pi \times Ln(Pi) \qquad (1)$$

where: *Pi* – relative frequency of each species in the sample.

The water is little or not polluted if H' > 3; it is moderately polluted if 1 < H' < 3; it is very polluted if H' < 1, according to Wilhm (1975).

Pielou's evenness index (E) (1975) serves to quantify the evenness or homogeneity of species distribution within the sample (Benjamin et al., 2024), according to the formulas from Equation 2 and Equation 3:

$$Evenness\ E = \frac{H'}{Hmax} \qquad (2)$$

$$H\ max = Log2\ (S) \qquad (3)$$

where: *H'* – Shannon index, *S* – overall species count.

Ranging between 0 and 1, this index (E) reflects distributional uniformity. The nearer the figure is to 1, the greater the parity in species abundances.

Statistical analysis

All statistical analyses were performed using XLSTAT (version 2024) and Jamovi software (version 2.6.17). Prior to analysis, data were tested for normality using the Shapiro–Wilk test, and for comparison, we used Wilcoxon's test.

To evaluate spatial and seasonal differences in physicochemical parameters, organic pollution index (IPO), and diatom-based indices (IDG, IPS, IDSE), with data not following a normal distribution, the Wilcoxon signed-test was used for several pairwise comparisons.

Relationships between physicochemical variables, IPO, and diatom indices were assessed using Spearman's rank correlation coefficient due to potential non-normality of ecological data.

To explore the overall structure of environmental gradients and diatom community responses, principal component analysis (PCA) was performed on centered and standardized variables. The significance of principal components was assessed based on eigenvalues (>1) and explained variance.

All statistical tests were considered significant at $p < 0.05$. Data are presented by wet and dry season, and the number of samples (21) is reported for each station and season.

RESULTS AND DISCUSSION

Spatiotemporal distribution of physicochemical parameters of watercourses

The results of the physicochemical parameters between the wet and dry seasons of the year 2024 are given in Table 3. Seasonality reveals higher temperatures in the dry season (mean value ≈ +10–12 °C between the wet and dry periods), and often a higher electrical conductivity (EC) in the dry season, a typical signature of concentration by evaporation and by continuous inputs of discharges.

Marked spatial heterogeneity – some stations (e.g., EM2, H2, M2) have very high ECs (several thousand at >10.000 µS/cm) and highly variable nutrient loads (NO_3^-, PO_4^{3-}, NH_4^+) and suspended solids (SS). An O_2/BOD_5 trend – at stations where the BOD_5 increases, a decrease in dissolved O_2 is often observed, which suggests O_2 consumption by organic degradation.

The analysis of the data indicates a thermal regime conducive to local aquatic communities (Rodier et al., 2009), a pH that is generally close to neutral to slightly alkaline. In addition, high loads of SS (>80–200 mg· L^{-1}) lead to a reduction in light penetration and consequently photosynthesis.

According to the classification of Handa (1969), the conductivities measured in these rivers fall within the brackish (1000 to 1500 µS/cm) and saline (1500 to 10,000 µS/cm) ranges. In accordance with the Moroccan normative framework (SEEE, 2002), 66% of the stations exceeded the conductivity threshold for the very bad quality class (>3000 µS/cm).

Relationships between diatom indices, pollution, and the ecological status of watercourses

The different parameters for assessing the ecological status of watercourses are represented in Table 4: the diatom indices (IDG, IPS, IDSE), the organic pollution index (IPO), the percentages of species resistant to organic pollution and anthropogenic eutrophication (%OP, %AE), the Shannon-Weaver diversity index (H') and the Pielou equitability index (E) as well as the ecological status and trophic status.

To perform the statistical tests on our data, normality was checked by the Shapiro-Wilk test. The results obtained ($p < 0.05$) showed that none

Table 3. Spatial variation of the physicochemical parameters of the study stations

Station	Season	T °C	pH	SS mg/L	EC µS/cm	SO_4^{2-} mg/l	O_2 mg/L	BOD_5 mg/L	PO_4^{3-} mg/l	NO_3^- mg/L	NH_4^+ mg/L
N1	Wet	15.3	8	54.2	1780	52	6.72	2.79	3.8	30	3.69
	Dry	27	7.5	15.2	2420	70.3	5.04	0.2	1.81	39.7	0.81
N2	Wet	14.7	7.95	19.5	1860	68	4.3	4.31	3.81	54.2	35.6
	Dry	26	7.8	17.2	1450	89	7.9	1.4	0.764	21.2	3.96
EM1	Wet	16.3	8.65	10.6	3970	152	9.88	2.2	0.02	0.741	0.021
	Dry	25.7	8.3	7.75	4120	116	7.78	2.45	0.02	0.03	0.02
EM2	Wet	14.8	7.6	47.3	4320	312	1.13	69.7	4.81	0.457	49
	Dry	25.1	7.95	19.4	4620	153	3.36	5.57	1.81	9.37	11.5
EM3	Wet	16.6	7.45	74	1970	88.1	1.42	129	3.16	0.844	38.8
	Dry	26.9	7.1	217	2930	38.3	0	199	11	0.717	104
H1	Wet	13.7	8.1	125	4410	285	6.48	11.7	2.26	7.28	10.1
	Dry	-	-	-	Dried up	-	-	-	-	-	-
H2	Wet	18.7	8.55	19.9	19150	490	11.7	9.33	0.02	2.81	1.14
	Dry	27.7	8.8	27.2	25800	824	8.92	7.98	0.035	3.44	0.545
B1	Wet	19.1	7.3	33.3	2330	126	3.22	8.1	1.63	4.11	5.76
	Dry	24.4	7.15	25.3	2240	94	6.3	1.97	0.11	16.9	0.644
B2	Wet	18.9	7.65	88.5	2360	127	1.18	37.3	1.99	0.144	24.5
	Dry	28.7	7.7	114	3650	153	0	45.6	1.9	0.478	25.2
M1	Wet	20.4	8.05	124	3690	142	0	93	6.57	1.47	88.6
	Dry	27.8	8.2	135	4990	213	4.16	63.7	6.33	0.3	67.6
M2	Wet	22.4	7.85	380	5870	196	0	191	1.93	1.35	51
	Dry	28.3	7.9	624	11000	104	0	629	18.3	0.3	632

of the indices follow the normal distribution. Thus, all the tests performed in the analysis of these indices are non-parametric tests (Wilcoxon test for the comparison of paired series and correlation test by the Spearman test).

At the level of the Nfifikh wadi, the N1 station has a poor ecological status and a persistent eutrophic status (IDG & IPS), correlated with high organic pollution as highlighted by the IPO during the two seasons. Downstream, the N2 station undergoes increased degradation with hypereutrophication and a very poor class, reflecting extreme inter-seasonal pollution. According to Merbouh et al. (2022) and the Hydraulic Basin Agency (ABHBC, 2022), this contamination is mainly attributable to domestic discharges and agricultural runoff.

The Wilcoxon test on the paired index series (wet/dry season) showed no significant difference between the two seasons ($p > 0.05$). For El Maleh, station EM1 has acceptable diatom indices (IDG=13.01; GPI=13.12; IDSE=3.6), revealing a low organic pollution/eutrophication (OP=17% / AE=16%) with an IPO of 4. This profile gives it an oligo-mesotrophic status and a good ecological status during the wet period. In dry periods, these indices drop sharply (IDG=10.47; IPS=9.88; IDSE=2.9), revealing strong eutrophication (AE=61%), despite low organic pollution (IPO = 4.25). This degradation leads to a reclassification in mesotrophic status and in moderate ecological status. While EM1 shows seasonal variations, EM2 maintains a persistent hypereutrophic status (poor class), correlated with very high organic pollution. EM3 shows a similar state in the wet period, but shows a slight seasonal improvement in the dry phase, moving from hypereutrophic to eutrophic.

As for Hassar, the H1 station has a poor ecological status and a eutrophic status, correlated with very high organic pollution (IPO=1.75). Although the IPO of 3.25 suggests moderate organic pollution at H2, the high abundance of resistant diatoms (OP = 65 to 83%) and the IPS and IDSE indices converge towards a different reality: a severe organic load consistent with the observed hypereutrophic status. This pollution is attributed to discharges from the riverside agglomerations and the Mediouna WWTP, as demonstrated by Nahli et al. (2019).

In addition, station B1, in the Bouskoura wadi, has a eutrophic status and a poor ecological status during the wet period, correlated with very heavy organic pollution (IPO=1.75). This situation is caused by wastewater discharge and negligence in waste management, causing water degradation, accentuated by eutrophication (ABHBC, 2024). In the dry season, a reduction in this pollution (IPO=3.25) is accompanied by an improvement in diatom indices, leading to a transition to mesotrophic status. B1 exhibits seasonal variations, unlike B2, which undergoes systemic degradation marked by persistent hyper-eutrophication and poor ecological status, revealing an upstream-downstream pollution gradient independent of seasonal cycles. This deterioration is mainly attributed to urban and industrial agglomerations that discharge their wastewater, as documented by the ABHBC (2024) in its note on the pollution of the Bouskoura wadi.

At Merzeg, very high levels of organic pollution affect the M1 and M2 stations, highlighted by the IPO and the %OP (correlated with the IDSE, see Table 4). At M2, the IDG and the IPS also corroborate this pollution. The convergence of these parameters attests to a persistent hyper-eutrophic status and a very poor ecological status, incompatible with a balanced or sustainable biodiversity. The origin of this severe degradation of the hydrosystem lies in the discharges from the Berrechid WWTP and the Had Soualem wastewater, identified by Mounjid et al. (2014) and the ABHBC (2019), without progress since. Except for some stations (EM1, B1), the indices reveal degraded ecological states with an upstream-downstream pollution gradient independent of seasonal cycles. Pairwise comparison of the data

Table 4. Results of indices and ecological status, with the strophic status of study stations

Station	Season	IPO	IDG	IPS	IDSE	% OP	% AE	H’	E
N1	Wet	2	7.59	5.61	2	77	2	1.77	0.48
	Dry	2,75	6.94	6.37	2.1	58	34	1.43	0.51
N2	Wet	1,75	2.21	2.41	1.3	91	8	0.94	0.31
	Dry	2,5	2.21	2.42	1.5	87	10	1.33	0.38
EM1	Wet	4	13.01	13.12	3.6	17	16	2.64	0.58
	Dry	4,5	10.47	9.88	2.9	28	61	1.05	0.32
EM2	Wet	1,5	3.55	2.59	1.3	83	1	0.99	0.29
	Dry	1,5	6.82	4.44	1.7	87	3	1.45	0.38
EM3	Wet	1,75	4.74	2.93	1.4	89	7	1.46	0.42
	Dry	1	10.43	7.01	2.3	62	15	1.62	0.54
H1	Wet	1,75	6.86	6.11	2.08	68	19	1.96	0.52
	Dry	Dried up							
H2	Wet	3,25	9.58	7.2	2.3	65	3	1.67	0.46
	Dry	3	5.36	3.67	1.6	83	5	1.42	0.47
B1	Wet	1,75	9.02	8.45	2.6	52	11	1.84	0.51
	Dry	3,25	10.17	9.17	2.7	34	21	2.53	0.55
B2	Wet	1,5	1.1	2.11	1.2	85	14	0.33	0.13
	Dry	1	2.64	2.49	1.3	79	14	1.06	0.27
M1	Wet	1,5	5.65	5.28	1.9	88	3	1.5	0.41
	Dry	1	5.89	5.72	2	78	3	1.55	0.4
M2	Wet	1	2.14	2.01	1.2	96	0	0.52	0.16
	Dry	1	2.17	2.24	1.3	96	0	0.54	0.17

Legend

Classes	I	II	III	IV	V
Trophic status	Oligotrophic	Oligo-Mesotrophic	Mesotrophic	Eutrophic	Hypertrophic
Ecological status	Very good	Good	Moderate	Poor	Bad

of the different indices according to upstream-downstream positioning by the Wilcoxon test showed a significant clear difference in the case of the IPS-IDSE indices (p=0.02) and no difference in the case of the IDG (p=0.074) and the IPO (p=0.236). The specific indices (IPS-IDSE) appear to be more sensitive to pollution than the IDG and the IPO.

The Spearman correlation test allowed a cross-analysis to be made between the 3 diatom indices (IDG, IPS, and IDSE), the organic pollution index (IPO), and the biodiversity indices (H', E) in Table 5. It shows that the most robust correlation is obtained between the IDSE and the IPS, with the highest rho of 0.99 and $p < 0.001$, indicating that these two indices are interchangeable in assessing organic loading.

The IPO index had highly significant correlations with the IDG, the IPS, and the IDSE. This result indicates that changes in diatom communities are a direct result of nutrient and organic matter inputs, as observed at most stations, which is consistent with what has been reported in the literature (Kumar and Nautiyal, 2024; Padula et al., 2021).

Distribution of the diatom community along the 11 surveyed stations

This study presents the first complete inventory of diatoms in the Atlantic basin of Greater Casablanca. Table 6 lists the species recorded in the five main wadis of the region: of the 11 stations sampled during the study period, 102 taxa, belonging to 44 genera, were identified. Of these, more than 13% are newly identified species for Morocco. *Nitzschia* is the most dominant genus at 20.51%, followed by *Navicula* (9.8%), then the genera *Fragilaria* (7.8%), *Amphora* (4.9%), and *Tryblionella* (4.9%). Species such as *Cocconeis placentula, Navicula cryptotenella, Nitzschia frustulum, Nitzschia palea,* and *Tryblionella hungarica* are the most frequent in almost all stations, with *Nitzschia palea* as the most abundant species.

Station B1 has a species richness (S) of 48 species dominated by *Nitzschia palea* (14%), *Nitzschia incospicua* (13%), *Achnanthes minutissima* (12%), and *Cocconeis placentula* (11%). Monitoring of station EM1 with a value of S = 44 species, of which *Navicula symmetrica* (57%) and *Fragilaria fasciculata* (12%) are the most dominant. The EM2 station has an S of 31 species, of which 56% are *Nitzschia palea,* followed by *Navicula subminiscula* (19%), *Gomphonema parvulum* (15%), *Navicula cryptotenella* (13%), and *Nitzschia incospicua* (13%). Station B2 has an S of 28 species with 41% of *Nitzschia palea,* 23% off *Nitzschia capitellata,* followed by *Nitzschia fonticola* (14%). The high prevalence of *Nitzschia palea, Nitzschia incospicua, Nitzschia capitellata, Navicula subminiscula, and Gomphonema parvulum* testifies to the high level of organic pollution experienced by these stations. This observation corroborates the studies carried out in Moroccan rivers by Fawzi et al. (2005) in the Wadi Hassar, Benhassane et al. (2020) in the Bouskoura wadi, and Jaghror et al. (2024) in the Wadi Sebou.

The N2 station has an S value equal to 27 species, predominated by Nitzschia palea (51%) and Nitzschia paleacea (20%), followed by EM3 with 26 species (S = 26), predominated by Nitzschia palea (53%) followed by Amphora coffeiformis (30%), then station H2 with S=25, dominated by *Amphora coffeiformis* (41%) followed by *Nitzschia palea* (32%) and *Cyclotella meneghiniana* (20%). The N1 station shows an S-value of 22 species dominated by *Navicula symmetrica* (27%), *Amphora coffeiformis* (21%), and

Table 5. Spearman's rho correlation coefficient calculated between the different indices (IPO, IDG, IPS, IDSE, H' & E) (N= 21)

Variables	IPO	IDG	IPS	IDSE	H'	E
IPO	**1**	—	—	—	—	—
IDG	0.56**	**1**	—	—	—	—
IPS	0.59**	0.98***	**1**	—	—	—
IDSE	0.61**	0.97***	0.99***	**1**	—	—
H'	0.39	0.79***	0.80***	0.80***	**1**	—
E	0.51*	0.80***	0.80***	0.82***	0.91***	**1**

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Nitzschia palea (20%). Station M1 with S = 22 is dominated by *Nitzschia incospicua* (23%), followed by *Nitzschia palea* (12%). 20 species at the H1 station dominated by Nitzschia palea (23%) and *Amphora coffeiformis* (16%). And finally, the M2 station has the lowest S value (16 species), dominated by Nitzschia palea (51%), followed by *Nitzschia incospicua* (16%).

The EM1 station has the highest generic diversity in wet periods (Shannon H' = 2.64; Pielou equitability E = 0.58), indicating a fairly homogeneous distribution of diatoms (Table 4). However, this diversity collapses radically in the dry season (H' = 1.05; E = 0.32), with heterogeneous dominance of *Navicula* correlated with severe eutrophication (AE = 61%) (Table 4). Station B1 reveals an opposite dynamic: during the wet period, a reduced diversity (H'=1.84) and dominated by the genus *Nitzschia* (E=0.51) is associated with high organic pollution (OP=52%). On the other hand, the dry season shows an improvement in diversity (H' = 2.53) with a fairly homogeneous distribution of diatom genera (E = 0.55), corresponding to a reduction in anthropogenic pressures (OP = 34% and AE = 21%).

The biodiversity values (H') observed at stations EM1 and B1, comparable to those reported in oligotrophic environments (Padula et al., 2021) despite local mesotrophic conditions, testify to a strong resilience of ecosystems.

Station B2 underwent a chronic collapse of its diatom diversity, reaching critical minima in wet periods (H' = 0.33; equitability E = 0.13). This degradation is directly attributable to extreme organic pollution (OP = 85%). The persistence of this pressure in the dry season (OP=79%) blocks any recolonization dynamic, maintaining diversity indices at dysfunctional levels (H'=1.06; E=0.27). Moreover, the M2 station shows a similar collapse, with indices of generic diversity that are constantly dystrophic (H' = 0.52–0.54; E = 0.16–0.17) over both seasons. This pathological stagnation is correlated with almost total organic pollution (OP = 96%), with anoxia ($O2$: 0 mg/l), revealing a permanently deteriorating ecological state.

Based on the classification of the Shannon-Weaver index given by Wilhm (1975), we find ourselves with only two cases: stations with moderate disturbances (N1, EM1, EM3, H1, H2, B1, and M1) and stations with very high pollution (N2, EM2, B2, and M2). However, this interpretation requires a cautious re-evaluation. The calculation of biodiversity indices (H', E) has been deliberately restricted to the generic level to avoid ecological bias. A high H' value (>3) and equitability (E ≈ 1), normally associated with good ecological status, would mask the dominance of tolerant taxa (*Nitzschia* spp.) in impoverished communities. This limitation, documented by Vilbaste (2004), confirms that these metrics are unsuitable for our case study. These results highlight the need to couple biodiversity indices with fine taxonomic analyses and specific bioindicators for a robust ecological assessment in altered environments.

Typology of diatom communities in the surveyed stations

Principal component analysis (PCA) was performed on a matrix of 33 diatom taxa (relevant species) and 11 additional stations with seven physicochemical parameters. It has made it possible to highlight the spatial organization of the assemblages of these taxa (Figure 2). The first two factor axes, F1 x F2, of the PCA account for 70.36% of the total information expressed by the data matrix (the acronyms in Table 6).

The F1 axis is positively associated with *Nitzschia dissipata* (NDIS), *Cymbella lanceolata* (CLAN), *Achnanthes minutissima* (AMIN), and negatively with *Nitzschia palea* (NPAL) and the physico-chemical variables revealing pollution. It seems to oppose the so-called rather polluo-tolerant species (*Nitzschia palea* (NPAL), *Navicula subminuscula* (NSBM), *Navicula venata* (NVEN)) to those moderately polluting-sensitive (*Cymbella affinis* (CAFF), *Cymbella lanceolata* (CLAN), *Nitzschia dissipata* (NDIS), *Rhoicosphenia abbreviata* (RABB), *Fragilaria brevistriata* (FBRE)). The F2 axis is positively associated with *Fallacia pigmea* (FPYG), *Achnanthes lanceolata* (ALAN), *Lemnicola hungarica* (LHUN), *Cymbella affinis* (CAFF).

The PCA reflecting the impact of anthropogenic disturbances in Greater Casablanca highlighted three distinct diatom clusters, inducing a partition into 3 groups of the 11 stations:

Group A, comprising stations N1, N2, EM2, EM3, H1, H2, B2, M1, and M2, is characterized by a diatom assemblage dominated by taxa indicating organic pollution and high hypereutrophy. This assembly includes, in particular: *Nitzschia incospicua* (NINC), *N. palea* (NPAL), *N. capitellata* (NCPL), *Gomphonema parvulum* (GPAR), *Cyclotella meneghiniana* (CMAN), *Hantzschia*

Table 6. List of taxa identified in the 11 study stations spread over the five wadis of Greater Casablanca

Taxa	Code	N1	N2	EM1	EM2	EM3	H1	H2	B1	B2	M1	M2
Achnanthes bioretii H.Germain	ABIO	-	-	-	-	-	-	-	+	-	-	-
Achnanthes brevipes var. intermedia (Kütz.) Clev*	AINT	-	-	-	-	-	-	-	+	-	-	-
Achnanthes delicatula (Kützing) Grunow	ADEL	-	-	-	-	-	-	-	+	-	-	-
Achnanthes lanceolata (Breb. ex Kütz.) Grunow	ALAN	-	-	-	-	-	-	-	+	-	+	-
Achnanthes minutissima Kützing	AMIN	+	-	+	-	-	-	-	+	-	-	-
Achnanthidium saprophilum (Kobayashi and Mayama) Round & Bukh.	ADSA	-	-	-	-	+	-	-	-	-	+	+
Amphora coffeiformis (C.Agardh) Kützing	ACOF	+	+	+	-	+	+	+	+	+	+	-
Amphora ovalis (Kützing) Kützing	AOVA	-	-	-	-	-	-	-	+	-	-	-
Amphora pediculus (Kützing) Grunow	APED	-	-	+	-	-	-	-	+	-	-	-
Amphora venata Kützing	AVEN	+	+	-	+	+	-	+	+	+	-	+
Anomoeoneis sphaerophora Pfitzer	ASPH	+	-	-	+	+	-	-	+	-	-	-
Aulacoseira pusilla (Meister) Tuji and Houki*	AUPU	-	-	-	-	-	-	-	+	-	-	-
Bacillaria paradoxa Gmelin	BPAR	-	+	+	+	+	+	-	+	+	-	-
Campylodiscus clypeus (Ehrenb.) Ehrenb. ex Kütz.	CCLY	-	-	+	-	-	+	+	-	-	-	-
Cocconeis placentula Ehrenberg	CPLA	+	+	+	+	-	+	+	+	+	+	+
Cyclotella meneghiniana Kützing	CMAN	-	+	-	+	+	-	+	+	+	+	-
Cylindrotheca closterium (Ehrenb.) Reimann and Lewin	CCLO	-	-	+	-	-	-	-	-	-	-	-
Cymatopleura elliptica W.Smith	CELL	-	-	+	-	-	-	-	-	-	-	-
Cymbella affinis Kützing	CAFF	-	-	-	-	-	-	-	+	-	-	-
Cymbella lanceolata (Agardh) Kirchner	CLAN	-	-	+	-	-	-	-	+	-	-	-
Cymbella pusilla Grunow	CPUS	-	-	+	-	-	+	-	-	-	-	-
Cymbella tumida (Bréb. ex Kütz.) Van Heurck*	CTUM	-	-	-	-	-	-	-	-	-	+	-
Diatoma problematica Lange-Bertalot	DPRO	+	-	-	-	-	-	-	-	-	-	-
Diploneis elliptica (Kützing) Cleve	DELL	-	-	-	-	-	-	-	+	-	-	-
Diploneis ovalis (Hilse) Cleve	DOVA	-	-	+	+	+	-	-	-	-	-	-
Entomoneis paludosa (W.Smith) Reimer	EPAL	-	-	+	+	+	-	-	+	-	-	-
Epithemia adnata (Kütz.) Brébisson	EADN	-	-	+	-	-	-	-	-	-	-	-
Epithemia gibba (Ehrenb.) Kütz.	EGIB	-	-	+	-	-	-	-	-	-	-	-
Epithemia musculus Kützing	EMUS	-	-	-	-	-	+	-	-	-	-	-
Eunotia trinacria Krasske	ETRIN	-	-	+	-	+	-	-	-	-	-	-
Fallacia pygmaea (Kütz.) Stickle and Mann	FPYG	+	+	-	+	+	-	+	+	+	+	-
Fallacia tenera (Hust.) Mann*	FTNR	-	-	-	-	-	-	-	+	-	-	-
Fragilaria brevistriata Grunow	FBRE	-	-	+	-	-	-	-	-	-	-	-
Fragilaria construens (Ehrenb.) Grunow	FCON	-	-	-	-	-	+	+	-	-	-	-
Fragilaria cyclopum (Brutschy) Lange-Bert.	FCYC	+	-	+	-	-	+	-	-	-	-	-
Fragilaria exiguiformis Lange-Bertalot*	FEXI	-	-	+	-	-	-	+	-	-	+	-
Fragilaria fasciculata (Agardh) Lange-Bert.	FFAS	-	-	+	+	+	+	-	+	-	-	-
Fragilaria pulchella (Ralfs ex Kütz.) Lange-Bert. (Ctenophora)	FPUL	-	-	-	-	-	-	-	-	+	-	-
Fragilaria tenera (W.Smith) Lange-Bertalot*	FTEN	-	-	-	+	-	+	-	-	-	-	-
Fragilaria ulna (Nitzsch) Lange-Bertalot	FULN	-	-	-	-	-	-	-	+	+	-	-
Geissleria decussis (Østrup) Lange-Bert. and Metzeltin	GDEC	-	-	+	-	-	-	-	-	-	-	-
Gogorevia exilis (Kütz.) Kulikovskiy and Kociolek	GEXI	-	-	+	+	-	-	+	+	-	+	+
Gomphonema gracile Ehrenberg	GGRA	-	-	+	+	-	-	-	+	-	+	-

Gomphonema parvulum (Kütz.) Kützing	GPAR	+	+	-	+	+	-	-	+	+	+	+
Gomphonema pumilum (Grunow) Reichardt and Lange-Bert.	GPUM	-	-	-	-	+	-	-	-	+	-	-
Gyrosigma acuminatum (Kütz.) Rabenhorst	GYAC	-	-	+	-	-	-	-	-	-	-	-
Gyrosigma obtusatum (Sullivant and Wormley) Boyer*	GYOB	-	-	-	+	-	-	-	-	-	-	-
Hantzschia amphioxys (Ehrenb.) Grunow	HAMP	-	+	-	+	-	-	-	-	+	+	+
Hippodonta hungarica (Grunow) Lange-Bert., Metzeltin & Witkowski	HHUN	+	-	+	+	-	-	-	+	-	-	-
Lemnicola hungarica (Grunow) Round and Bassoon	LHUN	-	-	-	-	-	-	-	+	+	-	-
Luticola nivalis (Ehrenberg) Mann	LNIV	-	+	-	-	-	-	-	-	-	-	-
Mastogloia braunii Grunow	MBRA	-	-	-	-	-	+	+	-	-	-	-
Navicula cryptocephala Kützing	NCRY	-	-	+	+	+	-	-	+	+	-	-
Navicula cryptotenella Lange-Bertalot	NCTE	+	-	+	+	+	+	+	+	+	+	+
Navicula duerrenbergiana Hustedt	NDUR	-	-	+	-	-	-	-	-	-	-	-
Navicula recens (Lange-Bert.) Lange-Bert.	NRCS	+	+	-	-	-	-	-	-	-	-	-
Navicula rhynchocephala Kützing	NRHY	+	-	+	-	-	-	-	+	-	-	-
Navicula salinarum Grunow	NSAL	-	+	-	-	-	-	-	-	-	-	-
Navicula subminuscula Manguin	NSBM	+	+	-	+	+	-	-	-	+	+	+
Navicula symmetrica R.M.Patrick	NSYM	+	-	+	-	-	-	-	+	-	-	-
Navicula veneta Kützing	NVEN	-	+	-	+	+	-	-	-	+	-	+
Navicula viridula (Kütz.) Ehrenberg	NVIR	-	-	+	-	-	-	-	-	-	-	-
Nitzschia acicularis (Kütz.) W.Smith	NACI	-	-	+	-	-	-	-	-	+	-	-
Nitzschia amphibia Grunow	NAMP	-	-	-	-	+	-	-	-	-	-	-
Nitzschia capitellata Hustedt	NCPL	-	+	-	+	+	-	-	+	+	-	-
Nitzschia clausii Hantzsch	NCLA	-	+	+	-	-	-	-	+	+	-	-
Nitzschia dissipata (Kützing) Rabenhorst	NDIS	-	-	+	-	-	-	-	+	-	-	-
Nitzschia elegantula Grunow	NELE	+	-	-	-	-	+	+	-	-	+	+
Nitzschia exilis Sovereign*	NEXI	-	-	+	-	-	-	-	-	-	-	-
Nitzschia filiformis (W.Smith) Van Heurck	NFIL	-	-	-	-	-	+	+	-	-	-	-
Nitzschia fonticola (Grunow) Grunow	NFON	-	+	-	+	+	-	+	-	+	-	-
Nitzschia frustulum (Kütz.) Grunow	NIFR	+	+	+	+	+	+	+	+	+	+	+
Nitzschia inconspicua Grunow	NINC	+	+	-	+	+	-	+	+	+	+	+
Nitzschia linearis (Agardh) W.Smith	NLIN	-	+	-	-	-	-	-	-	-	-	-
Nitzschia microcephala Grunow	NMIC	-	-	-	-	-	-	-	+	+	-	-
Nitzschia palea (Kützing) W.Smith	NPAL	+	+	+	+	+	+	+	+	+	+	+
Nitzschia paleacea (Grunow) Grunow	NPAE	-	+	-	-	-	-	-	-	-	-	+
Nitzschia recta Hantzsch	NREC	-	+	-	-	-	-	-	-	-	-	-
Nitzschia reversa W.Smith	NREN	-	-	+	-	-	-	-	-	-	-	-
Nitzschia serpentiraphe Lange-Bertalot*	NZSE	-	-	-	-	-	-	+	-	-	-	-
Nitzschia sigma (Kützing) W.Smith	NSIG	-	+	+	-	-	-	-	-	-	+	-
Nitzschia siliqua Archibald*	NSIL	-	+	-	-	-	-	-	-	-	-	-
Nitzschia umbonata (Ehrenb.) Lange-Bert.	NUMB	-	+	-	+	+	-	+	-	+	+	+
Plagiotropis lepidoptera (Gregory) Kuntze	PLEP	-	-	-	-	-	-	-	+	-	-	-
Pleurosigma delicatulum W.Smith*	PDEL	-	-	-	-	-	-	-	+	-	-	-
Pleurosira laevis (Ehrenb.) Compère	PLAE	-	-	+	-	-	+	-	+	-	-	-
Pinnularia appendiculata (C.Agardh) Schaarschmidt	PAPP	-	-	-	-	-	-	+	-	-	-	-
Psammothidium scoticum (Flower and Jones) Bukht. and Round*	PSCO	-	-	-	+	-	-	-	-	-	-	-

Reimeria sinuata (Greg.) Kociolek and Stoermer	RSIN	-	-	-	-	-	-	-	+	+	-	-
Rhoicosphenia abbreviata (C.Agardh) Lange-Bert.	RABB	+	-	+	-	-	-	-	-	-	-	-
Seminavis ventricosa (Greg.) M.Garcia-Baptista	SVEN	-	-	-	-	-	-	-	+	-	-	-
Stauroneis nobilis Schumann	SNOB	-	-	+	-	-	-	+	-	-	-	-
Staurosirella pinnata (Ehrenb.) Williams and Round*	SPIN	-	-	-	-	-	+	-	-	-	-	-
Surirella brebissonii Krammer and Lange-Bert.	SBRE	-	-	-	+	-	-	-	-	-	-	-
Surirella ovalis Brébisson	SOVI	-	-	+	-	+	-	-	-	-	+	+
Surirella splendida (Ehrenb.) Ehrenberg*	SSPL	-	-	-	-	-	-	-	+	-	-	-
Tryblionella apiculata W.Gregory	TAPI	+	-	-	-	-	-	-	+	-	-	-
Tryblionella calida (Grunow) Mann	TCAL	-	-	-	-	-	-	+	+	+	-	-
Tryblionella gracilis W.Smith	TGRA	-	-	-	+	-	-	+	+	-	-	-
Tryblionella hungarica (Grunow) Frenguelli	THUN	+	+	+	+	+	+	+	+	+	+	-
Tryblionella levidensis W.Smith	TLEV	-	-	-	+	-	-	-	-	-	-	-
Ulnaria delicatissima (W.Smith) Aboal and Silva	UDEL	-	-	+	-	-	+	+	-	-	-	-
Species richness	S	22	27	44	31	26	20	25	48	28	22	16

Note: *: newly identified species, +: presence, -: absence.

amphioxys (HAMP), *Navicula veneta* (NVEN), *N. subminuscula* (NSBM), and *N. cryptotenella* (NCTE). These stations are distinguished by significantly higher concentrations of organic matter, nutrients (nitrogen, phosphorus), and dissolved minerals (Table 3), indicating marked anthropogenic disturbance. The predominance of the above-mentioned taxa, recognized in the literature for their high polluotolerance and their affinity for eutrophic and frequently hypoxic environments (Benhassane et al., 2020; Jaghror et al., 2017), is consistent with these degraded environmental conditions.

Group B, mainly associated with station B1, is dominated by taxa indicating mesotrophic conditions, such as: *Fallacia pygmea* (GPYF), *Achnanthes lanceolata* (ALAN), *Lemnicola hungarica* (LHUG), *Cymbella affinis* (CAFF), *Gogorevia exilis* (GEXI), *Amphora pediculus* (APED), *Achnanthes delicatula* (ADEL), *Achnanthes minutissima* (AMIN), *Achnanthes bioretii* (ABIO), *Cocconeis placentula* (CPLA), and *Cymbella lanceolata* (CLAN). This site has an intermediate ecological status characterized by a moderate organic load, mesosaprobe oxygenation (O_2: 3–6 mg/l), and transitional nutrient concentrations reflecting an interface zone between anthropogenic disturbances and resilience processes. The predominance of these taxa, documented for their moderate tolerance to anthropogenic stresses and their ecological optimum in waters of average quality (Almeida et al., 2014), corroborates this ecosystem recovery gradient. As reported by Jachniak and Jaguś (2023), *Achnanthes lanceolata* prefers waters with oligotrophic or oligo-mesotrophic oxygenation*;* *Cocconeis placentula* and *Cymbella affinis* prefer good quality waters, as documented by Becer et al. (2017). The study of Noga et al. (2025) revealed a codominance of *Cocconeis placentula* and *Achnanthes minutissima* in mesotrophic environments, reflecting their shared adaptation to ambivalent environmental conditions.

Group C identifies the EM1 station, which includes *Campilodiscus clypeus* (CCLY), Cymatopleura elliptica (CELL), Fragilaria brevistriata (FBRE), Fragilaria fasciculata (FFAS), Diploneis ovalis (DOVA), Epithemia adnata (EADN), *Epithemia gibba* (EGIB), *Gyrosigma acuminatum* (GYAC), *Nitzschia dissipata* (NDIS), *Navicula duerrenbergiana* (NDUR), *Navicula symmetrica* (NSYM), *Rhoicosphenia abbreviata* (RABB). This site has: a low organic load ($BOD_5 < 3$ mg/L) and nutrient load ($PO_4^{3-} < 0.1$ mg/L; NO_3^-: 0.03–0.7 mg/l), high mineralization (EC: 3000–4000 µS/cm) of geological origin and optimal oxygenation (O_2: 7–9 mg/L; saturation > 85%) corresponding to an oligo-mesotrophic status, an indicator of preserved ecological integrity. The observation of *Entomoneis paludosa, Surirella ovalis* in this station in association with *Campilodiscus clypeus, Epithemia (Rhopalodia) gibba,*

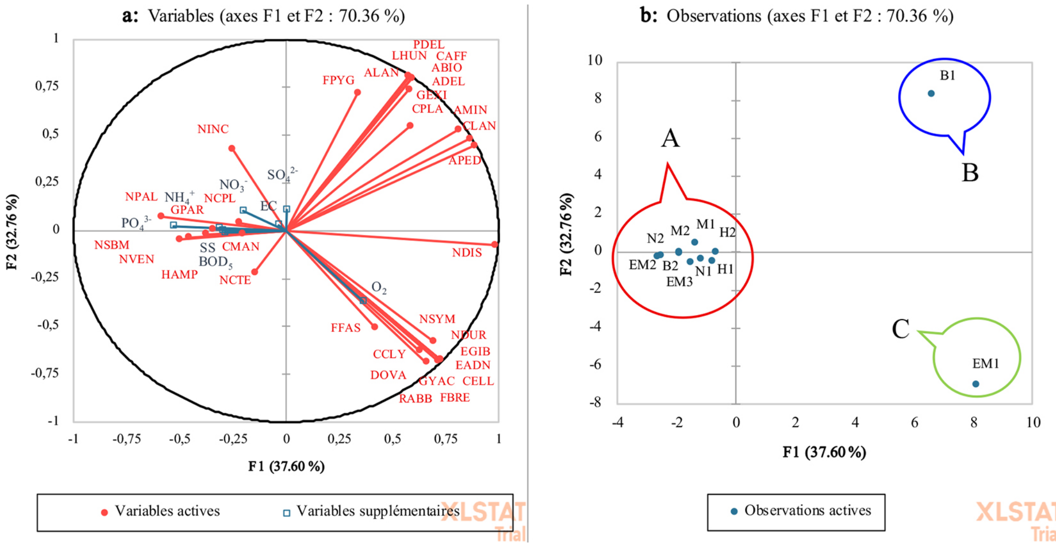

Figure 2. Projection on the F1 × F2 factorial level of the diatom taxa (a) and the 11 surveyed stations (b) concerning the 5 wadis of Greater Casablanca

Cymatopleura elliptica, which are euryhaline or even halophilic species, testifies to the degree of salinity of the water (Ruck et al., 2016).

The diatom flora identified, including *Amphora coffeiformis*, *A. veneta*, *Cylindrotheca closterium*, *Fragilaria fasciculata*, *F. pulchella*, *Gyrosigma acuminatum*, *Hantzschia amphioxys*, *Navicula duerrenbergiana*, *N. salinarum, Tryblionella hungarica, Nitzschia palea,* and *Pleurosira laevis*, is characteristic of media with high conductivity and high salinity (Cazaubon and Badri, 1994; Fawzi et al., 2005; Ouballouk et al., 2026). These species, mostly halophilic, are frequently reported in studies of Mediterranean coastal waters: the Adriatic Sea (Car and Kaleli, 2025) and the Mar Chica Lagoon (El Madani et al., 2011).

Diatoms illustrate complex relationships between morphology and autoecology: Some species have autoecological similarities, such as *Surirella ovalis,* which prefers electrolyte-rich waters and is mainly limited to brackish habitats, while *S. brebissonii* (EM2) tolerates medium to high electrolyte levels and is present in both brackish and freshwater environments (Krammer and Lange-Bertalot, 1987). Other species share morphological similarities masking distinct ecological preferences, such as *Achnanthes minutissima* (B1, EM1), which prefers oligo-mesotrophic waters, and *Achnanthidium saprophilum* (EM3, M1, M2) that thrives in eutrophic to hypereutrophic waters (Mayama and Kobayasi, 1984). Finally, cryptic species *(Nitzschia frustulum* and *N. inconspicua*) combine morpho-ecological proximity and difficult discrimination under a light microscope (Fawzi et al., 2005), addressing the taxonomic challenges related to diatom bioindication.

On the other hand, while physicochemical parameters provide an instantaneous but ephemeral diagnosis of disturbances, bioindicators offer an integrated perspective: their resilience to transient stresses and their ability to record historical disturbances make it possible to assess cumulative impacts on aquatic biota, a dimension absent from conventional physicochemical monitoring (Haidar et al., 2025; Benoît-Chabot, 2014).

While this study provides valuable insights, there are some limitations that need to be highlighted. The absence of comparable data for all seasons and all wadis, due to difficult access conditions during winter or droughts in autumn, limits the temporal representativeness of our results.

CONCLUSIONS

The results obtained demonstrate that the ecological assessment of the wadis of Greater Casablanca was achieved through a coherent integration of physicochemical descriptors, organic pollution indices, and diatom-based bioindication. The combination of these approaches provided a consistent and convergent diagnosis of water quality across all investigated hydrosystems, confirming the validity of the applied methodological framework.

The initial hypothesis regarding the existence of a marked upstream–downstream degradation gradient in diatom community structure is confirmed, as community composition and ecological indices systematically deteriorate downstream in response to increasing anthropogenic inputs. This degradation upstream-downstream is corroborated by the results of the Wilcoxon test, specifically for IPS and IDSE. The second hypothesis, according to which pollution is higher in summer than in winter, is only partially confirmed. While some stations show a concentration of pollutants in summer, others, on the contrary, have better water quality, creating variable situations per station. In addition, no significant difference has been demonstrated by the tests. The third hypothesis concerning the correlation between diatom indices and physicochemical/organic pollution descriptors is also confirmed, with consistent responses observed between IPS, IDG, IDSE, and IPO, demonstrating the reliability of diatom assemblages as integrative indicators in semi-arid Mediterranean river systems. The fourth hypothesis is partially confirmed, since while pollution-tolerant taxa dominate strongly impacted stations, intermediate assemblages also persist under certain high-conductivity conditions, indicating that tolerance patterns are not solely driven by nutrient load but also by salinity and mineralization stress. Finally, the fifth hypothesis is confirmed, as the combined use of multiple diatom indices provided a more discriminant and ecologically stable classification than any single metric alone, particularly in transition zones where individual indices produced divergent interpretations.

A key scientific outcome of this study lies in the identification of a consistent tripartite ecological structuring of the wadis of Greater Casablanca at the regional scale, where distinct assemblage types correspond to clearly differentiated functional states ranging from relatively preserved oligo-mesotrophic conditions to severely degraded hypereutrophic systems. This structuring emerges as a robust regional signature of cumulative anthropogenic pressure in Atlantic Moroccan hydrosystems, which has not previously been documented at the scale of an integrated multi-wadi system.

The study fills a critical gap in diatom-based ecological assessment in North African coastal basins by providing the first harmonized, multi-system dataset linking diatom assemblages, organic pollution gradients, and ecological status across interconnected wadis. It establishes a baseline reference for future comparative assessments in similarly impacted semi-arid environments and opens perspectives for developing region-specific diatom calibration frameworks adapted to high salinity and mixed anthropogenic pressures typical of Atlantic Moroccan catchments.

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