Journal of Applied and Natural Science
17(3), 1373 - 1385 (2025)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Determination of the ecological quality of Oued Nfifikh and Oued El Maleh (Morocco) using the generic diatomic index and the global normalized biological index

Nassur Said Ali HAIDAR*
Laboratory of Chemistry-physics and biotechnologies of biomolecules and materials (CP2BM), Faculty of Sciences and Techniques Mohammedia, University Hassan II of Casablanca, Morocco
MESKINI Nadia
Laboratory of Chemistry-physics and biotechnologies of biomolecules and materials (CP2BM), Faculty of Sciences and Techniques Mohammedia, University Hassan II of Casablanca, Morocco
LAKHIARI Hamid
Laboratory of Chemistry-physics and biotechnologies of biomolecules and materials (CP2BM), Faculty of Sciences and Techniques Mohammedia, University Hassan II of Casablanca, Morocco
MESSAOURI Hafida
Laboratory of Chemistry-physics and biotechnologies of biomolecules and materials (CP2BM), Faculty of Sciences and Techniques Mohammedia, University Hassan II of Casablanca, Morocco

*Corresponding author. E-mail: nassur.haidar-etu@etu.univh2c.ma

Article Info
https://doi.org/10.31018/jans.v17i3.6798
Received: May 02, 2025
Revised: August 29, 2025
Accepted: September 09, 2025

How to Cite
Haidar, N.S.A. *et al.* (2025). Determination of the ecological quality of Oued Nfifikh and Oued El Maleh (Morocco) using the generic diatomic index and the global normalized biological index. *Journal of Applied and Natural Science*, 17(3), 1373 - 1385. https://doi.org/10.31018/jans.v17i3.6798

Abstract
The quality of rivers and water reserves has now become a major concern due to the combined effects of climate change and human activities, which contribute to their degradation. This study assesses the water quality of four sites in Greater Casablanca, located upstream and downstream of two wadis: the Oued El Maleh dam (M1), its downstream in Mohammedia (M2), the Oued Nfifikh discharge area (N1), and its downstream (N2). The samples targeted diatoms and macroinvertebrates to calculate two biotic indices: the Generic Diatomic Index (GDI) and the Global Normalized Biological Index (GNBI), which were then compared to the Organic Pollution Index (OPI) determined by physicochemical analyses. The results revealed that the M1 site has a high diversity of diatoms (H' = 2.63), bio-indicators of good ecological quality (*Achnanthidium, Cymbella,* etc.), confirmed by a GDI of 13.01 (moderately eutrophic state) and an OPI of 4.3. On the other hand, the M2, N1, and N2 sites show low diatom diversity (H' = 1.46; 1.77; 0.94) and the presence of pollution-tolerant species (*Bacillaria paradoxa, Nitzschia palea*, etc.), with low GDIs (4.74; 7.59; 2.21) indicating pollution. The dominance of resistant taxa (gastropods at M2, hirudinae at N1, chironomidae at N2) and weak GNBI (4, 3, 2) confirm this degradation, as do OPIs (1.5; 2; 1.75). These results revealed that only M1 maintains a good ecological status, while M2, N1, and N2 are polluted, reflecting the impact of urban and industrial discharges. This deterioration highlights the need for effective management measures to protect these aquatic ecosystems, particularly in areas downstream of urban centers where anthropogenic pressures are increasing.

Keywords: Bio-indicators, Diatoms, Macroinvertebrates, Organic pollution, Water quality

INTRODUCTION

Currently, the world is facing water scarcity. The latter is suffering, on the one hand, from the effects of climate change, such as rising temperatures, drought, and a lack of rainfall, and on the other hand, from further deterioration of its drinking quality, as mentioned by El Morabet *et al*. (2024). The main sources of water pollution include domestic wastewater discharges, industrial effluents, and the intensive use of pesticides and chemical fertilizers in agriculture, as noted by the authors (Adjagodo *et al*., 2016). These pollutants disrupt aquatic ecosystems, leading to the disappearance of certain plant and animal species, as well as an imbalance in the food chain after Adjagodo *et al*. (2016).

In some cases, the accumulation of organic matter promotes eutrophication of the environment with blooms or phytoplankton blooms, which can cause the deterioration of the aquatic environment, which would affect human health, as mentioned by Dedjiho *et al*. (2013).

The assessment of the quality of aquatic environments is based on the analysis of physicochemical parameters and on the analysis of bioindicators that inhabit these environments, such as fish, macroinvertebrates, and microalgae, particularly diatoms (bacillariophyceae) (Benhassane *et al*., 2020). These organisms are directly influenced by the chemical composition of the water, including pH, temperature, nutrient concentration (nitrogen and phosphorus) and the presence of organic matter. As a result, they are widely used for the biological and environmental assessment of water quality (Singh *et al*., 2018).

Concerning diatoms, the evaluation indices are the generic diatomic index (GDI), the diatomic biological index (DBI), and the Specific Pollutivity Sensitivity Index (SPI), etc. For macroinvertebrates, we have the Biological Monitoring Working Party (BMWP), the Water Framework Directive Biological Monitoring Working Party score system (WFD-BMWP), and the Multi-Metric Invertebrate Index (M2I2), as used in Mondy *et al*. (2021).

The present study aimed to assess the physicochemical status of the Nfifikh and El Maleh wadis, conduct an unprecedented inventory of local diatoms (a first for these rivers), and determine the ecological quality of their waters using the GDI (Coste *and* Ayphassorho, 1991) and GNBI indices (AFNOR, 2004). The results obtained were compared with physicochemical analyses to refine the assessment of water quality and to confirm the validity of bioindicators as a reliable monitoring method.

MATERIALS AND METHODS

Study sites

The locations of the four study sites in the Greater Casablanca area are shown in Fig. 1 and their characteristics are summarized in Table 1.

The Oued El Maleh dam (M1), built in 1930 in the municipality of Fedalat (in the Greater Casablanca), has an area of 1800 m^2. It was supposed to serve as drinking water in the city of Casablanca (Morocco). This site is located 30 km from the mouth of the wadi on the Atlantic Ocean at Mohammedia and 25 km southeast of Casablanca (El Morabet *et al*., 2024; MATIN, 2002). Downstream of the Oued El Maleh, there is the wetland (M2) 1 km from the mouth of the Atlantic.

The Nfifikh wadi is a coastal river in the Bouregreg and Chaouia watersheds (Morocco). It crosses many rural areas and receives different types of liquid and solid discharges from human activities (domestic wastewater discharge and agricultural discharge) that are environmentally harmful along the river. The upstream sampling site of Oued Nfifikh (N1) is located directly downstream of a landfill point. The sampling site downstream of Oued Nfifikh (N2) is located at the limit of the confluence zone between the continental waters and those of the Atlantic Ocean and is located about 0.5 km from the mouth of the Plage des Sablettes in Mohammedia (Merbouh *et al*., 2023).

Samples of benthic diatom biofilm, macroinvertebrates, and water for physicochemical analysis were collected

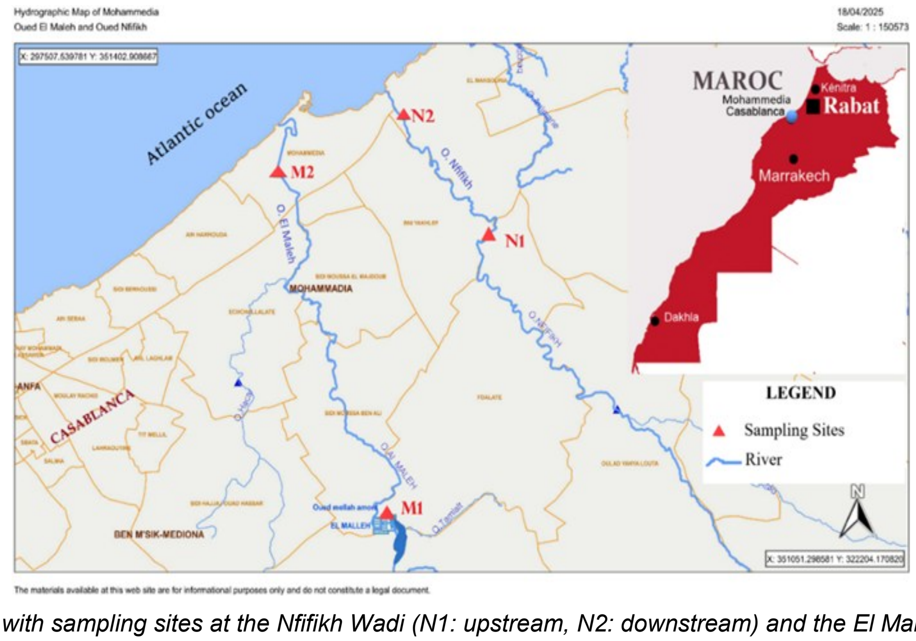

Fig. 1. *Study area with sampling sites at the Nfifikh Wadi (N1: upstream, N2: downstream) and the El Maleh Wadi (M1: upstream, M2: downstream)*

Table 1. Characteristics of the studied sites

Site	Commune	Wadis	Sampling site names	Lambert Contact Information		Type of possible pollution
				X	Y	
M1	Fedalat	El Maleh	Dam (Upstream)	319711	324847	Nothing to report
M2	Mohammedia		Wetland (downstream)	313337	344413	Agricultural Pollution and Wastewater
N1	Mohammedia	Nfifikh	After the discharge (Upstream)	325220	340210	Discharge
N2			Near the mouth (Downstream)	320092	348024	Wastewater

Table 2. Reference classes for the calculation of the organic pollution index (OPI) (Leclercq and Maquet, 1987)

Classes	NH_4^+ (mg/l)	BOD_5 (mg/l)	NO_2^- (µg/l)	PO_4^{3-} (µg/l)	OPI	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	High
1	>6	>15	> 150	> 900	1,0-1,9	Very High

simultaneously between spring (after rainfall) and autumn (before rainfall) in 2023.

Physicochemical parameter analyses

The water samples were collected from M1, M2, N1, and N2 for physical analyses in the field using a multi-parameter triple-inlet portable meter (HQ40d) to measure various parameters, including pH, temperature, dissolved oxygen (O_2), electrical conductivity, and turbidity. The speed of the stream was measured using a stopwatch and a floating plug that moved over a distance of 2 m.

Analyses of various chemical parameters, such as ammonium (NH_4^+), biological oxygen demand in 5 days (BOD_5), nitrite (NO_2^-), and phosphate (PO_4^{3-}), were carried out in accordance with the French standard (NFT 90-354, 2016) within the Laboratory.

Organic Pollution Index (OPI)

The OPI index proposed by Leclercq *and* Maquet (1987) was also used to assess the organic load of our study sites. This index is obtained based on the values of the four pollution parameters, namely NH_4^+, BOD_5, NO_2^-, and the PO_4^{3-}. The value of each parameter was compared with the reference table (Table 2) to identify the corresponding pollution class. The final organic pollution index was obtained by calculating the average of the pollution classes assigned to all the parameters, thus providing a synthetic assessment of the organic pollution present at the different sampling sites (Bekri *et al*., 2020).

Diatom sampling

Five natural substrates (such as pebbles, blocks) were generally used, which were then scraped to obtain the benthic diatom biofilm in a container. The contents of the container were then distributed into 50 mL graduated tubes, and 2 mL of Lugol's solution was added to each tube to preserve the diatoms (Lavoie *et al*., 2008; Almeida *et al*., 2014). The sampling process included the four sites, namely M1, M2, N1, and N2.

Chemical sample treatment

To degrade the organic matter, a volume of 5 mL of sample was incubated at 200°C in the presence of 10 mL of 40% hydrogen peroxide (H_2O_2) for 2 to 4 hours or more, depending on the raw state of the sample after Marezza *et al*. (2021). If the appearance of the sample remained reddish due to iron oxide, the preparation was first treated with a few drops of sulphuric acid (SA) for 5-10 minutes. Subsequently, all samples underwent a treatment with a few drops of hydrochloric acid (HCL) for 5 minutes to complete the cleaning by digesting the remaining mineral matter (Lavoie *et al*., 2008).

These treatments made it possible to highlight the ornamentation of the frustules (Strias, Raphes, Capitules, fibulae, ribs, etc.) necessary for the identification of diatoms.

Microscopic analysis and identification of diatoms

Visualization was carried out using an optical microscope (x40-x100 objectives) linked to a computer with a digital camera, enabling the capture of images. From these photos, and based on the attributes obtained by the ornamentation of the frustules on the one hand and the estimation of the cell dimensions carried out using the ImageJ software after calibration on the other, various classification keys were used to specify the genus in question (Spaulding *et al*., 2021; Rumeau *and*

Table 3. Reference Classes of the generic diatom index (GDI) and Biological Quality (Coste and Ayphassorho, 1991)

GDI	Biological quality	Ecological Characteristic
GDI ≥17	Very good	Low eutrophication
13 – 16	Good	Moderate eutrophication
9 - 13	Moderate	Moderate pollution or strong eutrophication
5 - 9	Poor	High Pollution
GDI < 5	Very poor	Very high pollution

Table 4. Reference Classes of the global normalized biological index (GNBI) and Biological Quality (AFNOR, 2004)

GNBI	Biological quality	Ecological Characteristic
GNBI ≥17	Very good	Low eutrophication
13 - 16	Good	Moderate eutrophication
9 - 12	Moderate	Strong eutrophication
5 - 8	Poor	High Pollution
GNBI ≤ 4	Very poor	Very high pollution

Coste, 1988).

Determining ecological status with the generic diatomic index (GDI)

To determine ecological status, a minimum of 400 individuals were counted under a microscope. The Diatomic Index N is first calculated and then converted to the GDI according to the following two equations:

$$N = \frac{\Sigma_{i=1}^{n} Si\, Vi\, Ai}{\Sigma_{i=1}^{n} Vi\, Ai} \quad (1)$$

$$GDI = N \times 4.75 - 3.75 \quad (2)$$

Si: Sensitivity class ranging from 1 for the most resistant to 5 for the most sensitive

Vi: Ecological amplitude of the genus varies, 1 = strong, 2 = medium, 3 = weak.

Ai: Workforce

The assessment of the ecological status of the freshwater environment on the basis of the GDI values varies from 1 to 20. These values are divided into five biological quality classes with map colours specific to each class (Table 3) as mentioned by Karim *et al*. (2017).

Determination of the specific diversity of diatom genera

The species diversity (H') of diatom genera was determined at the study sites, using the index of Shannon and Weaver (1963), which allows the heterogeneity of a given site to be measured by the following formula:

$$H' = -\sum_{i=1}^{s}(\mathrm{Pi} \times \mathrm{Ln(Pi)}) \quad (3)$$

Where:

Pi: relative frequency of each species in the sample

S: total number of species

This formula calculates diversity by considering both the abundance and richness of species. It reaches its minimum when all individuals are grouped in a single species, and its maximum when a different species corresponds to each individual.

The Pielou (1975) Fairness Index is used to calculate the equitability or uniformity of the distribution of species in the sample, based on the following two equations:

$$\mathrm{H\ max} = \mathrm{Log2\ (S)} \quad (4)$$

$$\mathrm{Equity\ E} = \frac{\mathrm{H'}}{Hmax} \quad (5)$$

H': Shannon's index

S: total number of species

The index H' varies from 0 to 1. The closer it is to 1, the more evenly the individuals are distributed among the species.

Sampling and identification of macroinvertebrates

The samples were taken between spring (after precipitation) and autumn (before precipitation) of 2023. The sampling protocol and the calculation of the GNBI were defined by the AFNOR standard (GNBI – NF T90-350) (AFNOR, 2004).

Samples were taken using a 500 µm diameter suber net. The contents of the net were transferred to bins to collect the macroinvertebrates. The latter were preserved in 10% formalin (Menbohan *et al*., 2010).

The calculation of the GNBI was based on 8 samples taken in different ecological niches, with a depth ≤ 1 metre. The harvested macroinvertebrates were identified according to the identification guide for the main freshwater benthic macroinvertebrates in Quebec (Moisan, 2010) and the key to determining freshwater macroinvertebrates (Freshwater invertebrates — Eduterre, n.d.).

The results were expressed as a score from 1 to 20, divided into five biological quality classes of the GNBI with a cartographic colour associated with each of them (Table 4).

Statistical analysis

The raw statistical data were centred and reduced, and then processed by Principal Component Analysis (PCA) to reduce its dimensions in the form of a graph by projecting it onto two main axes (PHILIPPEAU, 1986). The software used was XLSTAT (2024) version 4.2.

RESULTS AND DISCUSSION

Variation in the physical parameters of the sites

The results of the physical water parameters measured *in situ* are summarized in Table 5. The water temperature at the level of the Nfifikh wadi (N1 and N2) had an average of 15°C. As for Wadi El Maleh, temperatures were slightly higher than Wadi Nfifikh, with an average of 16.4 °C. This difference could be explained by a denser vegetation cover along the Oued Nfifikh, offering protection from direct sunlight, unlike the Oued El Maleh, as documented elsewhere (Kalny *et al*., 2017).

Concerning the pH, the values obtained were relatively homogeneous in the different sites, highlighting the buffering effect of the carbonate-bicarbonate complex (CO_3^{2-} - HCO_3^-). This effect is influenced by several factors, including the nature of the soil, the presence of aquatic vegetation, and anthropogenic activities (Merbouh *et al*., 2022). The mean was 7.9, with a more alkaline value observed at site M1 (8.5). According to Moroccan surface water standards (MNES) (SEEE, 2007), these sites were classified as having excellent water quality.

The measured electrical conductivity varies from 1450 µS/cm at the N1 site to 3780 µS/cm at the M1 site. According to Moroccan standards, sites N1 and N2 are classified as having average quality (1300 to 2700 µS/cm), while sites M2 and M1 have a quality considered poor to very poor (2700 to 3000 µS/cm) (SEEE, 2007). Indeed, the El Maleh wadi has a particularly high conductivity, especially upstream. This is probably due to the influence of the salt-bearing geochemical composition of the soil through which the stream flows. The conductivity decrease observed at the level of the wetland downstream of the wadi was attributed to wastewater discharge from the Mohammedia industrial zone and groundwater (Serghini *et al*., 2013).

Turbidity ranged from 22.5 to 130 NTU between M1 and M2, respectively. Stations N1 and N2 had moderate turbidity levels, with values ranging from 30 to 33 NTU. As far as dissolved oxygen was concerned, an extremely low value was recorded at the M2 site with a value of 0.2 mg/L, indicating a high level of organic matter pollution. This is consistent with the high turbidity observed, likely originating from industrial discharges (industrial zone) and agricultural runoff from the city of Mohammedia in Morocco (Guellaf *and* Kettani, 2025). Conversely, the M1 site had a high concentration of dissolved oxygen (9.38 mg/L), reflecting good water quality. According to Moroccan standards, the M2 site was classified as having very poor water quality (O2 < 1 mg/L), while the M1 site corresponds to water of excellent quality (O2 > 7 mg/L). The N1 and N2 sites had dissolved oxygen concentrations ranging from 6.7 to 4.3 mg/L, corresponding to good and average water quality, respectively, according to National criteria.

As far as the flow velocity is concerned, the highest values were recorded at the levels of sites M2 and N1. Site N2 had rather low speed, due to the influence of the tide, which limited the flow. The M1 site was characterised by an almost zero flow velocity, even stagnant, due to the presence of a dam upstream.

Chemical parameters

Organic Pollution Index

The concentrations of the main chemical parameters required to calculate the organic pollution index, namely NH_4^+, BOD_5, NO_2^-, and PO_4^{3-}, are shown in Table 6. The classification of organic pollution was based on the values obtained from the OPI.

Comparison between the different sites reveals that the M2 site had the highest values for BOD_5 (58.9 mg/L), ammonium (72 mg/L), and phosphate (5380 mg/L). These high values, combined with an extremely low dissolved oxygen level (see Table 5), suggested a very high level of organic and mineral contamination. These results were corroborated by a particularly low OPI value (1.5), which is characteristic of a very high level of pollution.

The very high nitrite concentrations distinguished the N2 site among all the sites studied (3930 µg/L). High levels of nitrite in a watercourse are generally associated with pollution from agricultural, industrial, or domestic sources, as mentioned by Picetti *et al*. (2022). The simultaneous presence of high nitrite and phosphate (3810 µg/L) levels also suggested mineral contamination. The site's OPI was 1.75, which confirms the presence of very high pollution (Table 6). According to the

Table 5. Physical parameters of the study sites

Site	T °C	pH	EC µS/cm	Turb NTU	O_2 mg/L	V cm/s
M1	16,3	8,5	3780	22,5	9,38	1 - 6
M2	16,6	7,6	2710	130	0,2	26 - 75
N1	15,3	7,8	1450	30	6,72	26 - 75
N2	14,7	7,95	1860	33	4,3	6 - 25

Basin Hydraulic Agency (ABHBC, 2022) and Merbouh *et al*. (2022), domestic waste and agricultural runoff are the main causes of this contamination.
On the other hand, in the M1 site, the level of pollution was low with a DB05 value of 4.35 and very low values for all the chemical parameters analyzed (NH_4^+, NO_2^-, and PO_4^{3-}). The high OPI of 4.33 indicated a low level of organic pollution and suggested good water quality at this site.

Generic Diatomic Index

Site-specific diatomic identification and analysis

Table 7 lists the taxonomic list, the relative abundance of species, and the varieties of diatoms inventoried at the study sites.
Upstream of the El Maleh wadi (M1), 25 different genera of diatoms had been identified with 35 species, 4 of which were characteristic of waters of good ecological quality (*Achnanthidium*, *Cymatopleura, Cymbella,* and *Stauroneis*). The highest frequencies corresponded to the species of *Navicula symmetrica*, *Navicula cryptotenella,* and *Epithemia gibba* with percentages of 19.16%, 7.85% and 8.76% respectively. The presence of *Campylodiscus clypeus, Gyrosigma acuminatum,* and *Navicula duerrenbergiana,* which are euryhaline species, highlighted a strong mineralization of the watercourse of the El Maleh wadi (Car *and* Kaleli, 2025).
Downstream of the El Maleh wetland wadi (M2), the site contained 11 genera, including 21 species of diatoms. Three pollution-indicator species dominated: *Nitzschia palea,* which accounts for 53%, *Navicula subminuscula,* to 9.35% and *Cyclotella meneghiniana* with 7.94% of individuals. Other species, such as *Amphora coffeiformis, Amphora venata, Bacillaria paradoxa, Fallacia pigmea, Gomphonema parvulum,* were also indicative of severe organic and mineral pollution, as reported by Fawzi *et al* (Fawzi *et al*., 2005).
As for the upstream Nfifikh wadi (N1), 13 genera with 18 species of diatoms were recorded, dominated by 4 species, namely *Amphora coffeiformis (*21%), *Gomphonema parvulum* (16.02%), *Navicula cryptotenella* (16.45%), and *Nitzschia palea* (14.5%). The strong proliferation of *Navicula subminuscula, Gomphonema parvulum, Nitzschia palea,* as well as the complex consisting of *Nitzschia frustulum* and *Nitzschia inconspicua,* reflected the degraded state of these waters.
In the downstream of the Nfifikh wadi (N2), only 8 different genera were found with 16 species, including a strong predominance of pollution indicator genera (70%). These genera were represented by *Nitzschia palea* (31,46%), *Nitzschia paleacae* (20,42%), *Nitzschia incospicua* (7.92%), and *Hantzschia amphioxys* (9.58%), as well as *Amphora venata, Fallacia pigmea, and Navicula venata,* with low abundances. These species show the degree of pollution of this watercourse.
The presence of *Navicula salinarum* confirmed elevated salinity at this site due to the proximity of the sea and its influence (maritime influence) (Hazelaar *et al*., 2005).

Biological quality and ecological character of the sites studied according to the GDI

The results presented in Table 8 showed that the M1 site was distinguished by good ecological quality, characterized by a GDI of 13.01 and moderate eutrophication. On the other hand, sites N1, M2, and N2 had significantly lower GDIs (7.59, 4.74, and 2.21, respectively), reflecting a degraded ecological status, ranging from poor to very poor. These low GDI values were associated with significant to very strong pollution downstream of the two wadis, accompanied by a pronounced eutrophication phenomenon. Intensive agricultural practices in these rural areas lead to increased accumulation of mineral and nutrient pollutants, linked to the leaching of fertilizers and pesticides, as mentioned by Guellaf *and* Kettani (2025).
Table 7 shows a strong disparity between the sites in terms of diatom species diversity. The M1 site was distinguished by the highest Shannon diversity index as well as the Pielou equitability index (H' = 2.63; E = 0.57), indicating a notable taxonomic richness. This diversity confirmed the good ecological quality of this site, already evidenced by the high values of the bioindicators: a GDI of 13.01, revealing a good ecological status with moderate eutrophication, and an OPI of 4.33, indicating low organic and mineral pollution. These results corroborated the observations of Merbouh *et al*. (2022), according to which the waters upstream of the wadis are generally of better quality than those downstream, which are often degraded by anthropogenic pressures.

Table 6. Organic pollution parameters of different sites with the Organic pollution index (OPI)

Site	NH_4^+ mg/L	BOD_5 mg/L	NO_2^- µg/L	PO_4^{3-} µg/L	OPI	Organic pollution
M1	0,031	4,35	0,021	20	4,33	Low
M2	72	58,9	19	5380	1,5	Very High
N1	3,69	2,79	2060	3800	2	High
N2	35,6	4,31	3930	3810	1,75	Very High

NH_4^+: ammonium, BOD_5: biological oxygen demand in 5 days, NO_2^-: nitrite, and PO_4^{3-}: phosphate

Table 7. Taxonomic list and relative abundance of diatom species and varieties inventoried at the study sites

Family	Genera	Species	Acronym	M1	M2	N1	N2
Achnanthidiaceae	*Achnanthidium*	*Achnanthes minutissima*	AMIN	3,65		0,43	
Catenulaceae	*Amphora*	*Amphora coffeiformis*	ACOF	4,93	1,17	21,21	
		Amphora pediculus	APED	2,74			
		Amphora venata	AVEN		0,47	1,08	0,42
Anomoeoneidaceae	*Anomoeoneis*	*Anomoeoneis sphaerophora*	ASPH		1,40	0,65	
Bacillariaceae	*Bacillaria*	*Bacillaria paradoxa*	BPAR	0,73	5,84		0,42
Surirellaceae	*Campylodiscus*	*Campylodiscus clypeus*	CCLY	3,47			
Cocconeidaceae	*Cocconeis*	*Cocconeis placentula*	CPLA	3,10		1,95	
Stephanodiscaceae	*Stephanocyclus*	*Cyclotella meneghiniana*	CMAN		7,94		
Bacillariaceae	*Cylindrotheca*	*Cylindrotheca closterium*	CCLO	0,73			
Surirellaceae	*Cymatopleura*	*Cymatopleura elliptica*	CELL	1,09			
Cymbellaceae	*Cymbella*	*Cymbella lanceolata*	CLAN	2,01			
		Cymbella pusilla	CPUS	2,74			
Fragilariaceae	*Diatoma*	*Diatoma problematica*	DPRO			0,22	
Diploneidaceae	*Diploneis*	*Diploneis ovalis*	DOVA	1,64	0,47		
Entomoneidaceae	*Entomoneis*	*Entomoneis paludosa*	EPAL	0,91			
Rhopalodiaceae	*Epithemia*	*Epithemia ednata*	EADN	0,55			
		Epithemia gibba	EGIB	8,76			
Eunotiaceae	*Eunotia*	*Eunotia trinacria*	ETRI	0,91			
Sellaphoraceae	*Fallacia*	*Fallacia pigmea*	FPYG		3,74	1,73	0,83
Fragilariaceae	*Fragilaria*	*Fragilaria cyclopum*	FCYC	0,55		0,22	
		Fragilaria fasciculata	FFAS	3,65			
Naviculaceae	*Geissleria*	*Geissleria decussis*	GDEC	0,91			
Achnanthidiaceae	*Gogorevia*	*Gogorevia exilis*	GEXI	0,55			
Gomphonemataceae	*Gomphonema*	*Gomphonema gracile*	GGRA	1,64			
		Gomphonema parvulum	GPAR		4,44	16,02	0,42
		Gomphonema pumilum	GPUM		0,70		
Pleurosigmataceae	*Gyrosigma*	*Gyrosigma acuminatum*	GYAC	4,56			
Bacillariaceae	*Hantzschia*	*Hantzschia amphioxys*	HAMP				9,58
Naviculaceae	*Hippodonta*	*Hippodonta hungarica*	HHUN	0,36		0,43	
Naviculaceae	*Navicula*	*Navicula cryptocephala*	NCRY	2,74	2,34		
		Navicula cryptotenella	NCTE	7,85		16,45	
		Navicula duerrenbergiana	NDUR	0,55			
		Navicula salinarum	NSAL				6,46
		Navicula subminuscula	NSBM		9,35	6,49	2,92
		Navicula symmetrica	NSYM	19,16			
		Navicula venata	NVEN		0,70		1,25
Bacillariaceae	*Nitzschia*	*Nitzschia acicularis*	NACI	1,09			
		Nitzschia amphibia	NAMP		0,47		
		Nitzschia capitellata	NCPL		0,47		
		Nitzschia elegantula	NELE			3,25	
		Nitzschia fonticola	NFON		1,64		2,92
		Nitzschia frustulum	NIFR		0,93	3,25	
		Nitzschia incospicua	NINC		0,93	5,63	7,92
		Nitzschia palea	NPAL	1,28	53,50	14,50	31,46
		Nitzschia paleacae	NPAE				20,42
		Nitzschia recta	NREC				4,58
		Nitzschia regula v. robusta	NRRO		1,17		5,63
		Nitzschia renversa	NREN	0,91			
		Nitzschia signa	NSIG	0,55			0,42
Rhoicospheniaceae	*Rhoicosphenia*	*Rhoicosphenia abbreviata*	RABB	4,93		0,65	
Stauroneidaceae	*Stauroneis*	*Stauroneis nobilis*	SNOB	5,11			
Surirellaceae	*Surirella*	*Surirella ovalis*	SOVI	1,64	0,47		
Bacillariaceae	*Tryblionella*	*Tryblionella hungarica*	THUN	2,37	1,87	5,84	4,38
Fragilariaceae	*Ulnaria*	*Ulnaria Delicatissima*	UDEL	1,64			
Taxonomic richness				**35**	**21**	**18**	**16**
Shannon-Weaver diversity index (H')				**2,63**	**1,46**	**1,77**	**0,94**
Pielou Equity index (E)				**0,57**	**0,42**	**0,48**	**0,31**

In contrast, site N2 had the lowest species diversity with the lowest equitability index (H' = 0.94; E = 0.31), indicating a marked ecological alteration. Similarly, sites M2 and N1 showed low diversity, with a predominance of pollution-tolerant diatom genera such as *Amphora, Gomphonema,* and especially *Nitzschia*. The ecological indices calculated for these sites confirmed their poor to very poor ecological status: the GDI values were 7.59 (N1), 4.74 (M2), and 2.21 (N2). The organic pollution index (OPI) supported these results, with values of 2.00 (N1), 1.50 (M2), and 1.75 (N2), respectively, reflecting significant contamination, particularly in organic and mineral matter.

Global Normalized Biological Index

Identification of macroinvertebrates by sites

Upstream of the El Maleh wadi (M1), a total of 348 individuals were identified, 76% of which belong to taxa recognized as indicators of pollution (Table 9). These organisms were distributed in a relatively balanced way between three groups: molluscs (gastropods), representing 28% of the sample, considered to be moderately polluting-tolerant, as were bivalves (28%) and chironomids (25%), widely recognized for their high tolerance to degraded environments. The presence of baetidae (4.31%), a group with low polluting tolerance, nevertheless testified to a certain residual ecological diversity (Nahli *et al*., 2019).

Downstream of the El Maleh wadi, a wetland (M2) among the 65 individuals collected, gastropods represented 30% of the community, followed by ceratopogonidae (26%), a group of insects adapted to muddy and muddy substrates (Zimmer *et al*., 2014). Chironomidae (20%) and Gammaridae (16%) were among the low-polluting and resistant taxa. Indeed, these taxa had a high proliferation capacity in waters rich in organic matter and poor in dissolved oxygen, as was shown by the physicochemical parameters shown in Tables 5 and 6.

At the upstream level of the Nfifikh wadi (N1), this site revealed the presence of 183 Macroinvertebrates, dominated by chironomidae (58%), followed by hirudinae (31%), two groups that are highly tolerant to pollution. Baetids, which are not very polluting-tolerant, represent only 6% of the individuals recorded, which reflects a degraded aquatic biodiversity.

In the downstream of the Nfifikh wadi (N2), a total of 221 individuals were collected, mostly Diptera. Chironomidae were the most abundant (60%), followed by culicidae (29%) and to a lesser extent syrphidae and oligochaetes (5%). All of these taxa are highly resistant to organic and mineral pollution. The presence of *Eristalis tenax* (Syrphidae), often associated with environments rich in organic matter, testified to the poor ecological state of this site.

The taxonomic richness observed in the sites, ranging from 6 to 10 taxa, was very low compared to other values reported in other studies, such as those carried out at the level of Wadi Za (in eastern Morocco), where a taxonomic richness of 16 taxa was recorded at a domestic wastewater discharge point, and where a taxonomic richness of 52 taxa was also observed in the upstream point devoid of disturbance (Fagrouch *et al*., 2011). Other higher values were also noted at the level of the Wadi Hassar, ranging from 51 to 60 taxa (Nahli *et al*., 2019). This indicates that the less disturbed environments had a higher richness.

This low taxonomic richness, combined with the dominance of polluting-resistant taxa, reflected a significant degradation of the biodiversity of the rivers studied. This observation was accentuated by the low flow velocity observed on these sites, a consequence of the discontinuity of the watercourse in the case of the downstream of Wadi Nfifikh and the impact of the dam infrastructure for Wadi El Maleh. These conditions favoured sedimentation of suspended particles, accumulation of muddy deposits, and poor water oxygenation. Consequently, they prevented optimal self-purification of watercourses and created an environment unfavourable for pollution-sensitive species but conducive to proliferating resistant taxa like oligochaetes and Diptera.

Notably, work by Fagrouch *et al*. (2011) demonstrated that water at a Wadi Za discharge point remained well-oxygenated despite high BOD_5 and COD levels due to strong current velocity.

Biological quality and ecological character of the sites studied according to the global normalized biological index (GNBI)

The results of the Global Normalized Biological Index (GNBI), presented in Table 10, made it possible to assess the biological quality of the four sites studied. The M1 site had an index of 5, corresponding to poor biological quality. However, this same site had a good

Table 8. Biological quality and ecological characteristic of the 3 sites studied according to the generic diatom index (GDI)

Site	GDI	Biological quality	Ecological characteristic
M1	13,01	Good	Moderate eutrophication
M2	4,74	Very poor	Very high pollution
N1	7,59	Poor	High pollution
N2	2,21	Very poor	Very high pollution

ecological status according to the Generic Diatomic Index (GDI).

This contrast could be explained by the particular nature of the habitat: the dam environment, with depths reaching 20 meters, did not provide sufficient substrates suitable for macroinvertebrate collection, unlike diatoms, which benefited from more favourable conditions. It was noted, following AFNOR standard (2004), that the reference value of the GNBI (Generic Biodiversity Index) in undisturbed environments was generally close to 20. However, in specific typological contexts such as springs, small streams, slow-flowing areas, or large rivers, this value could naturally be lower without necessarily indicating anthropogenic degradation, as reported by Nahli *et al*. (2019). Consequently, the GNBI proved to be of limited relevance for assessing water quality in artificial or atypical contexts like dam reservoirs.

On the other hand, the GNBI values were 4, 3, and 2 for sites M2, N1, and N2, respectively. These low scores reflected severely polluted conditions across all three sites, associated with advanced eutrophication, though occurring within distinct ecological contexts.

Indeed, these habitats, rich in natural substrates and therefore highly biogenic, normally promoted the development of a diversified benthic fauna. Consequently, the depressed index values reflected genuine ecological degradation, primarily linked to organic and/or mineral pollution that had rendered these environments unsuitable for pollution-sensitive species proliferation.

Anthropogenic pressures were particularly marked at M2, where the site was exposed to untreated domestic and industrial discharges. This sector, in the urban area of Mohammedia, constituted a former landfill area, exposed to waste leaching, domestic wastewater, effluents from textile industries, as well as discharges from butchers' shops and the municipal slaughterhouse (Serghini *et al*., 2013 ; Kanbouchi *et al*., 2014). Similarly, the Nfifikh wadi crosses several rural and urban areas and was subject to the cumulative impact of solid and liquid discharges from multiple human activities located along its bed (Merbouh *et al*., 2020, 2023).

Finally, the GDI and OPI proved more coherent and representative of ecological quality than the GNBI. While effective under stable hydrological conditions, the GNBI demonstrated limitations in seasonally disturbed environments like Wadi El Maleh's dam reservoir or Wadi Nfifikh's low-flow periods. The GNBI, as well as the structure of the macro-benthic communities in the different sites, is based on criteria closely related to the structure of the habitat, the hydrological regime (including the substrate and the velocity of the current), the physicochemical characteristics, and the riparian vegetation. However, these criteria make GNBI less suitable for intermittent environments, unlike diatomic indices that are more resilient to these variations.

Principal component analysis

Principal Component Analysis (PCA) of chemical data associated with organic pollution, combined with diatom data, with macroinvertebrates as additional variables, revealed that 80.60% of the total variability of the data was explained by the F1 x F2 factorial design (Fig. 2).

The F1 axis (55.65% explained variance): This axis was mainly positively correlated with taxa sensitive to organic pollution, such as *Amphora pediculus* (APED), *Gogorevia exilis* (GEXI), *Achnanthes minutissima* (AMIN), *Cymbella lanceolata* (CLAN), *Epithemia gibba* (EGIB), *Cymatopleura elliptica* (CELL), *Campylodiscus clypeus* (CCLY), *Navicula duerrenbergiana* (NDUR), *Navicula symmetrica* (NSYM), as well as bivalves. It was negatively correlated with pollution-related parameters, such as PO_4^{3-}, and the taxa *Navicula subminuscula* (NSBM), *Nitzschia palea* (NPAL), *Fallacia pigmea* (FPYG).

The F2 axis (24.95% variance explained): This second axis, although less influential than the first, was positively correlated with nitrophilic and polluo-resistant taxa such as *Amphora coffeiformis* (ACOF), *Navicula cryptotenella* (NCTE), *Nitzschia elegantula* (IN IT), *Tryblionella hungarica* (THUN), as well as with groups of invertebrates such as hirudinea, chironomidae, and baetidae. Conversely, it showed a negative correlation with indicators of organic pollution, such as NH_4^+, BOD_5, *Bacillaria paradoxa* (BPAR), *Nitzschia capitellata* (NCPL), *Nitzschia amphibia* (NAMP), *Cyclotella meneghiniana* (CMAN), as well as with gammaridae (Fig. 2).

Site M1: It was positively positioned on the F1 axis and is associated with taxa sensitive to organic pollution that were *Achnanthes minutissima* (AMEN), *Amphora pediculus* (APED), *Cymatopleura elliptica* (CELL), *Epithemia gibba* (EGIB), and euryhaline taxa such as *Gyrosigma acuminatum* (GYAC), *Campylodiscus clypeus* (CCLY), *Entomoneis paludosa* (EPAL), *Cymbella pusilla* (CPUS), and *Navicula duerrenbergiana* (NDUR). These diatomaceous species reflected good ecological water quality with high conductivity (Table 5). These findings were corroborated by the work of Fawzi *et al*. (2005) at the level of the Wadi Hassar. The absence of chemical parameters related to organic pollution (BOD_5, NH_4^+, NO_2^-, PO_4^{3-}) and the presence of polluting -sensitive macroinvertebrates such as bivalves confirmed this result.

Site N1: Associated mainly with the F2 axis, characterized by the presence of pollutant-resistant and nitrophilic taxa (NO_2^-) such as the diatoms *Amphora coffeiformis* (ACOF), *Navicula cryptotenella* (NCTE), *Nitzschia elegantula* (NELE), *Tryblionella hungarica* (THUN), *Gomphonema parvulum* (GPAR), *Nitzschia*

Table 9. Relative abundance of taxonomic groups of macroinvertebrates collected from the sites

Taxa	M1	M2	N1	N2
Emb. ANNELIDES				
C. OLIGOCHETES*	0,86	-	-	5,43
C. PURCHASED (Hirudinea)*	-	-	31,69	-
Emb. ARTHROPODS				
C. INSECTS				
O. Mayflies				
*F. Baetidae**	4,31	-	6,56	-
O. Hemiptera (sO. Heteroptera)				
F. Corixidae	3,45	-	-	0,45
F. Nepidae	0,86	-	-	0,45
F. Gerridae	1,72	-	-	-
F. Hydrometridae	-	-	0,55	-
O. Diptera				
*F. Chironomidae**	25,86	20,00	58,47	60,63
F. Culicidae	-	-	1,64	29,41
F. Tabanidae	-	-	1,09	-
F. Ceratopogonidae	5,17	26,15	-	0,90
F. Anthomidae	-	1,54	-	-
F. Syrphidae	-	-	-	2,71
F. Ampididae	-	1,54	-	-
S. Emb. CRUSTACEA				
F. Atyidae	0,29	-	-	-
*F. Gammaridae**	-	16,92	-	-
Emb. MOLLUSCS				
C. GASTEROPODA*	28,74	30,77	-	-
C. BIVALVES*	28,74	3,08	-	-
Taxonomic richness	**10**	**7**	**6**	**7**

* indicates the bioindicator taxa; Emb: phylum, C: class, O: order, F: family

Table 10. Biological quality and ecological characteristic in terms of the global normalized biological index (GNBI) for the 4 sites studied

Site	GNBI	Biological quality	Ecological characteristic
M1	5	Poor	High Pollution
M2	4	Very poor	Very high Pollution
N1	3	Very poor	Very high Pollution
N2	2	Very poor	Very high Pollution

frustulum (NIFR), *Nitzschia incospica* (NINC), and macroinvertebrates such as hirudinea and chironomidae.
The association of GPAR, NCTE, and NIFR species in waters with marked eutrophication had already been reported by Taylor *et al*. (2007).
Sites M2 and N2 showed negative contributions to both the F1 and F2 axes. These sites were dominated by high concentrations of BOD_5, NH_4^+, and PO_4^{3-}, indicating significant organic pollution. This result was in agreement with polluo-tolerant taxa such as the diatom species *Cyclotella meneghiniana* (CMAN), *Fallacia pigmea* (FPYG), *Navicula subminuscula* (NSBM), *Navicula venata* (NVEN), *Nitzschia amphibia* (NAMP), *Nitzschia palea* (NPAL), *Nitzschia recta* (NREC), but also with the strong presence of macroinvertebrates such as gammaridae.
These sites were characterized by high concentrations of BOD_5, NH_4^+, and PO_4^{3-}, indicating significant organic pollution. These observations were consistent with the work of Benhassane *et al*. (2020) carried out on the Bouskoura wadi, as to the presence of these taxa in heavily polluted waters.
These observations were consistent with the work of Benhassane *et al*. (2020) on the diatoms of the Bouskoura wadi, which showed that the NAMP, NPAL, and NREC species were dependent on heavily polluted waters, and on the other hand, with the work of Fawzi (2005) on Oued Hassar, which associated the pres-

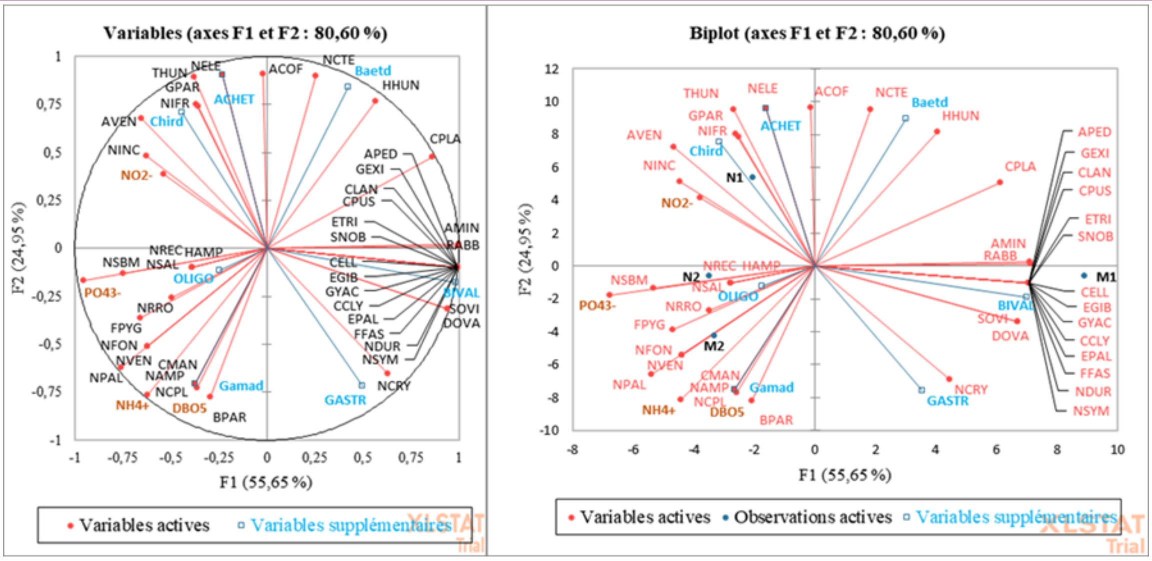

Fig. 2. *Representation of variables and sites on the F1 and F2 factorial plane (PCA) Achet: achètes, Baetd: baetidae, Bival: bivalves, Chird: chironomidae, Gamad: gammaridae, Gastr: gastropods, Oligo: oligochaetes*

ence of the NSBM diatomic species, GPAR, NIFR, NPAL, and NINC to high pollution.

Perspective

This promising preliminary work must be continued, on the one hand, by increasing the number of sampling sites according to the seasons. The use of the Diatomic Biological Index (DBI) (Prygiel *et al.*, 2002) and the Specific Pollution Sensitivity Index (SPI) (Blanco, 2024) are often used as a highly relevant international benchmark for characterizing the ecological status of rivers. Fish and macrophytes should also be considered as an additional component of biomonitoring of aquatic environments.

Conclusion

The conclusions of the three water monitoring Indices used, namely the two biological indices, GDI and GNBI, and the physicochemical index OPI, are complementary for a more holistic assessment of rivers. However, the advantage of bioindicators compared to physicochemical dosing was that the sampling of bioindicators proved easy to implement, inexpensive, and not very sensitive to sudden environmental variations. The generic diatom index and the normalized global biological index effectively highlighted the ecological status of the studied sites. The OPI confirmed this finding by highlighting the level of organic pollution affecting these sites. Thus, only site M1 was less impacted by organic pollution despite high mineralization, paradoxically compared to sites N1, N2, and M2, which are the most polluted. Consequently, site M1 was the most diverse in terms of diatom species compared to the other sites. It should also be noted that, unlike the IBGN, the IDG and OPI were more consistent and representative indicators of the ecological quality of the environments studied and better reflect local conditions. In terms of this first approach, which has highlighted the harmful effects of organic pollution on these 2 rivers (Nfifikh and El Maleh), it was crucial to highlight the negative impact of this pollution on aquatic biodiversity, as well as the health risks that this pollution implies for humans. Taking into account human activities such as swimming (Sablette beach at the level of the Nfifikh wadi), fishing, and the collection of bivalves (at the mouth of the El Maleh wadi wetland). In light of these findings, we urgently recommend the implementation of awareness campaigns for the ecological use of fertilizers upstream, the strengthening and strict enforcement of environmental regulations, and the launch of ecological restoration projects in the affected areas.

Conflict of interest

The authors declare that they have no conflict of interest.

Funding source

No funding was received to assist with the preparation of this study.

REFERENCES

1. ABHBC (2022). Bouregreg and Chaouia Water Basin Agency. Note on the mass fish mortality observed at the mouth of the Nfifikh River, near Sablettes Beach in Mohammedia, V 11-08-2022.
2. Adjagodo, A., Tchibozo, M. A. D., Kelome, N. C., & Lawani, R. (2016). Fluxes of pollutants linked to anthropogenic activities, risks to surface water resources and the trophic chain around the world: Bibliographic review. *International Journal of Biological and Chemical Sciences*, *10* (3), Article 3. https://doi.org/10.4314/ijbcs.v10i3.43

3. AFNOR. (2004, March). *Water Quality—Determination of the Global Normalized Biological Index (GNBI).* Afnor EDITIONS. https://www.boutique.afnor.org/fr-fr/norme/nf-t90350/qualite-de-leau-determination-de-lindice-biologique-global-normalise-GNBI/fa122108/22769
4. Almeida, S. F. P., Elias, C., Ferreira, J., Tornés, E., Puccinelli, C., Delmas, F., Dörflinger, G., Urbanič, G., Marcheggiani, S., Rosebery, J., Mancini, L., & Sabater, S. (2014). Water quality assessment of rivers using diatom metrics across Mediterranean Europe : A methods intercalibration exercise. *Science of The Total Environment*, *476□477*, 768□776. https://doi.org/10.1016/j.scitotenv.2013.11.144
5. Bekri, M., El Hmaidi, A., Jaddi, H., Ousmana, H., Kasse, Z., el Faleh, E. M., Essahlaoui, A., & El Ouali, A. (2020). Use of quality and organic pollution indices in the evaluation of the physico-chemical quality of the surface waters of the Moulouya and Ansegmir wadis (Haute Moulouya, NE of Morocco). *European Scientific Journal*, *16*, 55-75. https://doi.org/10.19044/esj.2020.v16n27p55
6. Benhassane, L., Oubraim, S., Mounjid, J., Fadlaoui, S., & Loudiki, M. (2020). Monitoring Impacts of Human Activities on Bouskoura Stream (Periurban of Casablanca, Morocco) : 3. Bio-Ecology of Epilithic Diatoms (First Results). *Nature Environment and Pollution Technology*, *19* (5(Supp)), 1913□1930. https://doi.org/10.46488/NEPT.2020.v19i05.016
7. Blanco, S. (2024). What do diatom indices indicate? Modeling the specific pollution sensitivity index. *Environmental Science and Pollution Research*, *31*(20), 29449□29459. https://doi.org/10.1007/s11356-024-33115-1
8. Car, A., & Kaleli, A. (2025). Marine benthic diatoms from the Adriatic Sea (NE Mediterranean) : Review of investigations and checklist with updated nomenclature. *Acta Botanica Croatica*, *84*(2), 0□0. https://doi.org/10.37427/botcro-2025-024
9. Coste, M., & Ayphassorho, H. (1991). A study of water quality in Artois-Picardie bassine with the help of benthic diatomia communities: An application of diatomic index. Report Cemagref Bordeaux, Agence de l'Eau Artois-Picardie, DouaiH
10. Dedjiho, C. A., Mama, D., Dimon, B. F., Chouti, W., Alassane, A., Fiogbe, E. D., & Sohounhloue, C. K. D. (2013). Influence of the eutrophication state of the Gbèzoumè lagoon (Ouidah) on its aquatic fauna. *International Journal of Biological and Chemical Sciences*, *7*(5), Article 5. https://doi.org/10.4314/ijbcs.v7i5.24
11. El Morabet, R., Barhazi, L., Bouhafa, S., Dahim, M. A., Khan, R. A., & Dahim, A. M. (2024). Water quality, heavy metal contamination and health risk assessment of surface water bodies of Mohammedia prefecture, Morocco. *Environmental Chemistry and Ecotoxicology*, *6*, 33□41. https://doi.org/10.1016/j.enceco.2023.12.002
12. Fagrouch, A., Berrahou, A., & El Halouani, H. (2011). Impact of an urban effluent from the city of Taourirt on the structure of macroinvertebrate communities in Wadi Za (eastern Morocco). *Journal of Water Sciences*, *24*(2), 87-101. https://www.erudit.org/en/journals/rseau/2011-v24-n2-rseau5003765/1006104ar/abstract/
13. Fassinou, N. M., Gouissi, F. M., Goura, S. O., Yessoufou, W. B., & Biaou, T. S. (2023). Impact of agricultural contamination on the physico-chemical and biological quality of surface waters: Bibliographic review. *International Journal of Progressive Sciences and Technologies*, *39*(1), Article 1. https://doi.org/10.52155/ijpsat.v39.1.5289
14. Fawzi, B., Chlaida, M., Oubraim, S., Loudiki, M., Sabour, B., & Bouzidi, A. (2005). Application of certain diatomic indices to a Moroccan river: Oued Hassar. *Journal of Water Sciences*, *14*(1), 73-89. https://doi.org/10.7202/705410ar
15. Hazelaar, S., Van Der Strate, H. J., Gieskes, W. W. C., & Vrieling, E. G. (2005). Monitoring Rapid Valve Formation in the Pennate Diatom Navicula Salinarum (bacillariophyceae). *Journal of Phycology*, *41*(2), 354□358. https://doi.org/10.1111/j.1529-8817.2005.04131.x
16. *Freshwater Invertebrates—Eduterre*. (n.d.). Retrieved May 14, 2024, from https://eduterre.ens-lyon.fr/thematiques/hydro/travail-coop/determin/identif?searchterm=classi
17. Guellaf, A., & Kettani, K. (2025). Assessment of seasonal variations in water quality and pollution sources in the coastal water bodies between Casablanca and Rabat (northwest Morocco). Ecological Engineering & Environmental Technology, 26(5), 323□336. https://doi.org/10.12912/27197050/203464
18. Kalny, G., Laaha, G., Melcher, A., Trimmel, H., Weihs, P., & Rauch, H. P. (2017). The influence of riparian vegetation shading on water temperature during low flow conditions in a medium sized river. Knowledge & Management of Aquatic Ecosystems, 5. https://doi.org/10.1051/kmae/2016037
19. Kanbouchi, I., Souabi, S., Chtaini, A., & Aboulhassan, M. A. (2014). Evaluation of the pollution of mixed wastewater collected by the sewerage network of the city of Mohammedia: Case of a main collector. *Laboratory Technologies*, *8*(34).
20. Karim, P. L., Kamel, D., Hamouche, D. A., & Nadjiba, M. B. (2017). *Contribution to the assessment of the water quality of Lake Réghaia by Generic Diatomic Index (GDI).*
21. Lavoie, I., Hamilton, P. B., Campeau, S., Grenier, M., & Dillon, P. J. (2008). *Guide to the Identification of Diatoms in Rivers of Eastern Canada* (1st ed.). Presses de l'Université du Québec. https://doi.org/10.2307/j.ctv18ph4tz
22. Leclercq, L., & Maquet, B. (1987). Two new chemical and diatom indices for assessing the quality of running water: application to the Samson and its tributaries (Belgian Meuse basin), comparison with other chemical, biocenotic, and diatom indices. Royal Belgian Institute of Natural Sciences.
23. Marezza, F., Marchetti, C., Lanzi, G., Lusetti, A., Bertani, A., & Cecchi, R. (2021). Diatom extraction: A new technique with heated H_2O_2. A technical note. *Legal Medicine*, *50*, 101861. https://doi.org/10.1016/j.legalmed.2021.101861
24. MATIN, L. (2002, November 29). *The press visits the site of the Oued El Maleh dam*. The Matin.ma. https://lematin.ma/journal/2002/La-presse-visite-le-site-du-barrage-de-Oued-El-Maleh/22930.html
25. Menbohan, S. F., Zebare, T. S. H., Nyamsi, T. N. L., & Njiné, T. (2010). Benthic macroinvertebrates of the Nga river: Characterization Essay of a Reference by Biological Analyses. *European Journal of Scientific Research*, *43*(1), 96-106.

26. Merbouh, C., Belhsaien, K., Zouahri, A., & Iounes, N. (2020). Evaluation of the physico-chemical quality of groundwater in the vicinity of the Mohammedia-Benslimane controlled landfill: (preliminary study). *European Scientific Journal*, *16*(6), 455-470.
27. Merbouh, C., Kabriti, M., Nahli, A., Rihane, A., & Iounes, N. (2023). Physicochemical Characterization and Metallic Contamination of the Waters of Oued Nfifikh (Morocco). *Ecological Engineering & Environmental Technology*, *24* (1), 1□11. https://doi.org/10.12912/27197050/154911
28. Merbouh, C., Namoussi, S., Kabriti, M., Naamane, A., Rihane, A., & Iounes, N. (2022). Physico-chemical characterization of an urban wastewater effluent and its impact on the receiving environment: Oued Nfifikh (Morocco). *Journal of Ecological Engineering*, *23*(3). https://doi.org/10.12911/22998993/145464
29. Moisan, J. (n.d.). *Guide to the Identification of the Main Freshwater Benthic Macroinvertebrates in Quebec, 2010 – Voluntary Monitoring of Shallow Watercourses*.
30. Mondy, C., Villeneuve, B., Archaimbault, V., & Usseglio-Polatera, P. (2021). A new generation of indicators: The example of the I2M2 multimetric invertebrate index. *Sciences Eaux & Territoires*, *37*, 30-37.
31. Nahli, A., Chlaida, M., & Said, O. (2019). Diversité taxonomique et structure du peuplement macrobenthique des eaux de l'Oued Hassar après installation de la station d'épuration de Mediouna (Casablanca, Maroc) Taxonomic diversity and structure of Hassar creek's macrobenthic community after Mediouna WWTP installation (Casablanca, Morocco). *Bulletin de l'Institut Scientifique*, *2018*, 37-56.
32. NF T90-354 (2016). Échantillonnage, traitement et analyse de diatomées benthiques en cours d'eau et canaux. Afnor EDITIONS. https://www.boutique.afnor.org/fr-fr/norme/nf-t90354/qualite-de-leau-echantillonnage-traitement-et-analyse-de-diatomees-benthiqu/fa182112/1564;
33. Philippeau, G. (1986). *How to interpret the results of a principal component analysis?* ITCF.
34. Picetti, R., Deeney, M., Pastorino, S., Miller, M. R., Shah, A., Leon, D. A., Dangour, A. D., & Green, R. (2022). Nitrate and nitrite contamination in drinking water and cancer risk : A systematic review with meta-analysis. *Environmental Research*, *210*, 112988. https://doi.org/10.1016/j.envres.2022.112988
35. Pielou, E. C. (1975). Ecological Diversity. John Wiley and Sons, New York, pp. 165. Limnology and Oceanography, 22(1). https://doi.org/10.4319/lo.1977.22.1.0174b
36. Prygiel, J., Carpentier, P., Almeida, S., Coste, M., Druart, J.-C., Ector, L., Guillard, D., Honoré, M.-A., Iserentant, R., Ledeganck, P., Lalanne-Cassou, C., Lesniak, C., Mercier, I., Moncaut, P., Nazart, M., Nouchet, N., Peres, F., Peeters, V., Rimet, F., & Zydek, N. (2002). Determination of the biological diatom index (IBD NF T 90-354) : Results of an intercomparison exercise. *Journal of Applied Phycology*, *14*, 27□39. https://doi.org/10.1023/A:1015277207328
37. Rumeau, A., & Coste, M. (1988). Introduction to the systematics of freshwater diatoms. For the practical use of a generic diatomic index. *Bulletin Français de la Pêche et de la Pisciculture*, *309*, 1-69. https://doi.org/10.1051/kmae:1988009
38. SEEE. (2007). *Secretary of State to the Ministry of Energy, Mines, Water and the Environment, in charge of Water and the Environment (SEEE 2007): Moroccan standards defining the surface water quality grid.* https://www.environnement.gov.ma/fr/78-cat1/1008-normes-de-qualite-des-eaux-de-surfaces
39. Serghini, A., Elabidi, A., El Blidi, S., & Fekhaoui, M. (2013). Spatio-temporal typology and hydrological functioning of the Mohammedia wetland complex (Morocco). *Bulletin de l'Institut Scientifique, Rabat*, *35*, 61-65.
40. Shannon, C. E., & Weaver, W. (1963). The Mathematical Theory of Communication, Univ. Illinois Press, pp. 117.
41. Singh, R., Nautiyal, P., & Nautiyal, R. (2018). Evaluation of the ecological state of the major streams located in Doon valley using diatoms as indicators. Journal of Applied and Natural Science, 10(1), Article 1. https://doi.org/10.31018/jans.v10i1.1658.
42. Spaulding, S. A., Potapova, M. G., Bishop, I. W., Lee, S. S., Gasperak, T. S., Jovanoska, E., Furey, P. C., & Edlund, M. B. (2021). *Diatoms.org* : Supporting taxonomists, connecting communities. *Diatom Research*, *36*(4), 291□304. https://doi.org/10.1080/0269249X.2021.2006790
43. Taylor, J. C., Prygiel, J., Vosloo, A., De La Rey, P. A., & Van Rensburg, L. (2007). Can diatom-based pollution indices be used for biomonitoring in South Africa? A case study of the Crocodile West and Marico water management area. *Hydrobiologia*, *592*(1), 455□464. https://doi.org/10.1007/s10750-007-0788-1
44. Zimmer, J.-Y., Haubruge, E., & Francis, F. (2014). Bibliographic synthesis: The larval ecology of culicoides (Diptera: Ceratopogonidae). *Biotechnology, Agronomy, Society and Environment*, *18*, 301-312.