EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(5), 96–105
https://doi.org/10.12912/27197050/185248
ISSN 2719-7050, License CC-BY 4.0

Received: 2024.02.16
Accepted: 2024.03.21
Published: 2024.04.01

Exploring the Utility of Macrophyte Metrics for Evaluating the Quality of Rivers in Morocco – Insights from the Macrophyte Biological Index for Rivers

Ayoub Nouri[1*], Soumaya Hammada[1], Khaffou Mhamed[2], Lahcen Chillasse[3]

[1] Laboratory of Agro-Industrial and Medical Biotechnologies, Faculty of Sciences and Techniques, Sultan Moulay Slimane University, Beni Mellal, Morocco

[2] Higher School of Technology, Sultan Moulay Slimane University, Khenifra, Morocco

[3] Laboratory of Environment, Ecology and Health, Faculty of Sciences, Moulay Ismail University, Meknes, Morocco

* Corresponding author's e-mail: ayoub_nouri@usms.ma

ABSTRACT

Macrophytes not only integrate environmental conditions but also reflect the trophic state of the aquatic environment through several metrics. The lack of knowledge on the biology and ecology of aquatic plants in Moroccan rivers makes it very difficult to establish a comprehensive and effective national metric for assessing the trophic state of rivers. Indeed, the use of one of the European methods, which have been the subject of geographical intercalibration projects across different countries, particularly those in the Mediterranean region, proves necessary. Given Morocco's geographic location within the Mediterranean Basin, Macrophyte Biological Index for Rivers (IBMR) was chosen as a method to assess Moroccan running waters. Furthermore, it allowed answering a number of questions about the usage of biological metrics based on macrophytic communities throughout Morocco. The obtained results showed that the IBMR can provide an indication of the overall trophic state of the watercourse, but with well-defined conditions, namely stable hydrological conditions with a significant richness in contributing pollution-sensitive species. Although this macrophyte index showed correlations with the parameters responsible for eutrophication phenomena, it remained less effective in the face of the downgrading parameter. Thus, the particular context of Moroccan watercourses, namely the watercourses of the Upper Oum Er-rbia basin, and the major pitfall that still lies in the knowledge of the ecology of plant groups in Moroccan running waters, can pose a problem in the application of the IBMR index, especially with regard to ubiquitous species that dominate the downstream sites of the studied rivers.

Keywords: macrophyte metric, IBMR, trophic state, Morocco, running water, Mediterranean Basin.

INTRODUCTION

Macrophytes are floristic groups the determinism of which is the basis of every biotypological or bioindication research (Dutartre et al., 2008; Haury et al., 2001). Most floristic typology investigations are based on the analysis of interactions between communities or macrophyte species and the factors affecting their environment. The concept of bioindication as applied to macrophytes requires the approaches that diverge from those traditionally explored in phytoecology or phytosociology. Previous studies on the aquatic environment and vegetation interaction could be regarded as a precursor to bioassessment methods. They highlighted the potency of macrophytes as bioindicators, which opened up opportunities for other researchers to propose and develop biological metrics, as well as sampling strategies for each approach. There are now many macrophytic metrics that differ based on the selected macrophyte communities. Trophic indices are the most common on an international scale. They are based on the presence and abundance of specific species. Each of them is assigned an indication value based on its tolerance to nutrient enrichment in the environment. In Europe, three trophic metrics based on macrophyte communities are frequently applied to assess water quality. The UK Environment Agency adopted the MTR index (Holmes et al., 1999). In Germany, the TIM index (Schneider and Melzer 2003). The Macrophyte Biological Index for Rivers (IBMR) was standardized in France in October 2003 under the reference NF T90-395. IBMR reflects the entire trophic degree of the watercourse, as it depends on nutrient concentrations (nitrogen and phosphorus), fermentable organic matter, and physical environmental parameters (Haury et al., 2006). When compared to the MTR index, the IBMR index shows several improvements, making it more efficient. The reduction of abundance classes in IBMR (five classes) versus MTR (nine classes) reduces the uncertainty caused by the operator's subjectivity in the field. Thus, by combining the coefficient of stenoecy of the taxa and the score of their affinity towards the trophic level of the environment, the bioindicator value and sensitivity of the taxa can be increased (Wiederkehr 2015) .

In addition to the methods mentioned above, many European countries concerned with the evaluation of the biological quality of watercourses have begun their reflection on the development of biomonitoring tools. They created their own metrics for assessing the ecological state of rivers, such as Macrophyte Index for Rivers (MIR) in Poland (Szoszkiewicz et al., 2020), IVAM and IMF in Spain (Flor-Arnau et al., 2015; Tomás, Pedro et al., 2016), the multimetric index in Cyprus (Pieterse et al., 2009), and various indices in other countries.

The challenges of eutrophication in aquatic systems, as well as the plant proliferations that are frequently associated with it, have necessitated an expansion of studies on the ecology of macrophytes and their bioindicator capacity. The results of these studies can be used to establish bioevaluation methods beyond diagnosis based on hydrochemical analyses as well as promote their use on a regional and national scale.

The lack of knowledge on the constituent groups of the macrophytic populations of Moroccan watercourses, especially bryophytes and algae, whose identification is often difficult, makes it very challenging to develop a complete and effective national method for the evaluation of the trophic state of watercourses. Indeed, the use of one of the European methods, which have been the subject of geographical inter-calibration projects between different countries, particularly the Mediterranean countries, proves necessary.

Due to Morocco's geographical location within the Mediterranean Basin, IBMR was chosen as a method for evaluating Moroccan running waters (Bentaibi et al., 2017; Nouri et al., 2021). Through these studies, researchers have aimed to bridge the knowledge gap regarding the biology and ecology of aquatic plants in Moroccan rivers. The current study was conducted within the same context and sought to test the reliability of the IBMR index in reflecting the trophic state of watercourses and the responses of macrophytic communities to various disturbances.

MATERIAL AND METHODS

Study area

The study area is located in the upper Oum Er-rbia watershed, which covers an area of 1531 km^2. It is a sub-basin of the larger basin of the Oum Er-rbia river, which originates in the central Middle Atlas and is an important water supply for Morocco (Fig. 1). Five rivers from the upper Oum Er-rbia basin were chosen for their hydrological functioning, which is common to the majority of Mediterranean watercourses, as well as their morphology. In this study, fourteen sites were chosen based on their current state and degree of disruption, as well as the IBMR standard requirements. The Oum Er-rbia river begins at an elevation of roughly 1300 meters and originates from lots of sources. Six sites along the main flow were chosen. It should be emphasized that several rivers in this region are being anthropized (farming, grazing, etc.), including those located directly downstream of water sources. There are few sites in the study area that are unaffected by human activities. Amengous is a tributary of the Fellat River. It originates in the Bekrit region, at an altitude of about 2000 meters. The Department of Water and Forests has classified it as a permanent fishing reserve. The Bekrit region is known for its farming practices, particularly fruit tree production. The Fellat river is one of the primary tributaries of the Oum Er-rbia river. It originates at an elevation of approximately 1800 meters before joining the Oum Er-rbia. The Ichbouka River is the principal tributary of the Srou River. It rises to 800 meters in the Aguelmame N'Miaami region before joining Oued Srou on the right bank.

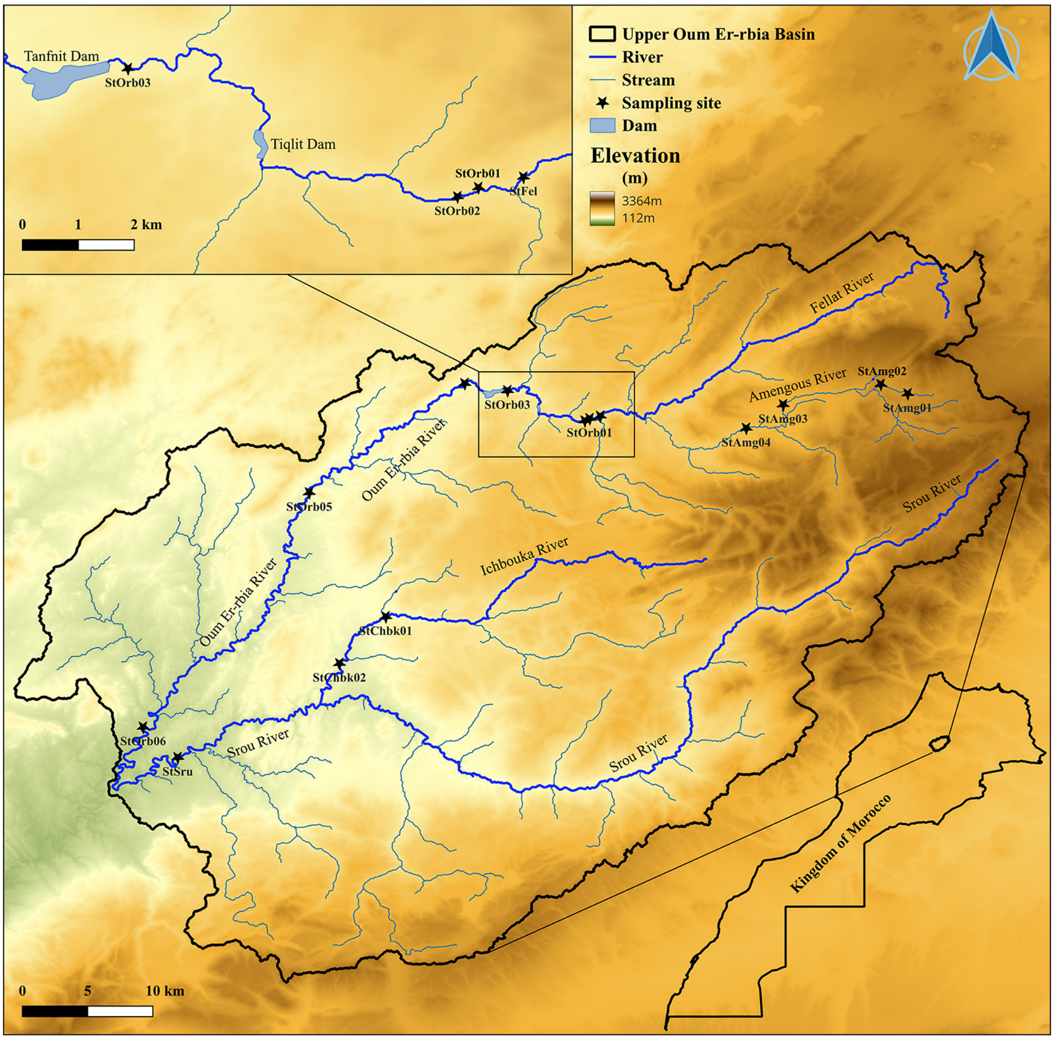

Figure 1. Locations of sampling sites in the Upper Oum Er-rbia basin

Sampling procedures

The study of macrophytic communities is based on the application of the IBMR sampling and observation protocol (NF T90-395). This standardized method defines a sampling and analysis strategy appropriate to watercourses. Fourteen stations throughout the Oum Er-rbia river and some of its tributaries were located for this study. Sampling was carried out during the optimal growth period (June 2018, July 2018, May 2019, and June 2019) in accordance with the IBMR standards. In order to evaluate the quality of the water, sampling is combined with physico-chemical analysis (Table 1).

Metric calculation

IBMR is calculated using a list of 208 aquatic taxa, which includes phanerogams (107 species), pteridophytes (3 species), bryophytes (52 species), lichens (2 species), macroalgae (42 genera), fungi, and filamentous bacteria (2 genera). The NF T90-395 standard provides, in addition to the reference list of taxa (known as contributing taxa), a series of variables that will be used to calculate the IBMR:

- specific score (CSi): reflects the trophic state, it varies from 0 (eutrophic tendency) to 20 (oligotrophic tendency) of each taxon;
- stenoecy coefficient (Ei): corresponding to the ecological amplitude of taxa. It ranges from 1 (wide amplitude) to 3 (very limited amplitude).
- coverage coefficients (Ki): classified into five coverage categories based on an estimate of the percentage of the surface occupied by macrophytes, varying from 1 to 5 (1: < 0.1%; 2: from 0.1 to < 1%; 3: 1 to < 10%; 4: 10 to < 50%; 5: > 50%).

IBMR is calculated according to the following formula:

Table 1. The physicochemical parameters of the water at the studied sites

Parameter		WT (°C)	EC (μs/cm)	DO (mgO_2/l)	NO_2-N (mg/l)	NH_3-N (mg/l)	PO_4^{3-} (mg/l)	NO_3-N (mg/l)	COD_{Mn} (mgO_2/l)	pH
StAmg01	June 2018	12.5	215	11.12	0.032	0.13	0.08	8.94	1.8	7.45
	July 2018	13	200	12.53	0.015	0.08	0.16	8.72	2.69	7.23
	May 2019	10.5	297	11.4	0.061	0	0.02	7.63	2.89	7.62
	June 2019	17.9	308	12.53	0.022	0.15	0	7.15	3.12	8.65
StAmg02	June 2018	13.4	378	10	0.045	0.12	0.19	8.23	1.6	7.45
	July 2018	13.5	374	7.16	0.018	0.02	1.46	8.26	3.85	7.41
	May 2019	14.7	395	10.86	0.034	0	0.15	8.43	3.72	7.74
	June 2019	16.8	421	13.56	0.016	0	0.08	7.93	2.14	8.72
StAmg03	June 2018	17.1	376	8	0.048	0.13	0.12	8.96	2.23	7.77
	July 2018	15.4	406	7.96	0.036	0.23	0	7.64	6.03	7.51
	May 2019	13.1	417	10.12	0.059	0	0.2	9.11	3.45	8.12
	June 2019	19.6	459	10.54	0.052	0.02	0.01	9.01	5.12	8.59
StAmg04	June 2018	17	689	8.2	0.044	0.01	0.2	10.36	4.16	7.6
	July 2018	17.8	685	7.84	0.015	0.02	0.25	9.87	8.02	7.47
	May 2019	12.4	632	10.54	0.036	0	0.29	6.65	3.12	7.43
	June 2019	23	693	10.14	0.028	0	0.1	6.23	2.75	8.24
StOrb01	June 2018	15	1505	9	0.016	0	0.08	7.46	2.88	7.38
	July 2018	15.7	1736	8.96	0.019	0.01	0.05	8.03	3.2	7.45
	May 2019	15.1	2008	9.07	0.01	0.02	0.31	10.05	2.64	8.04
	June 2019	15.6	1974	10.67	0.013	0	0.02	9.75	2.36	8.1
StOrb02	June 2018	15.7	1701	8	0.038	0.06	0.63	10.11	3.02	7.52
	July 2018	16.1	1810	8.64	0.023	0.05	0.58	10.11	3.24	7.46
	May 2019	15.5	2336	8.81	0.02	0.15	0.63	10.36	3.15	8.11
	June 2019	16.4	2308	10.32	0.009	0.15	0.59	10.46	3.96	8.22
StOrb03	June 2018	16.4	1714	8.4	0.013	0.18	0.52	9.08	3.84	7.45
	July 2018	17.3	2223	8.42	0.012	0.13	0.55	9.88	4.16	7.4
	May 2019	16.5	2513	9.21	0.032	0.08	0.08	8.11	4.38	8.14
	June 2019	19.2	2597	10.83	0.032	0.07	0.07	8.08	4.73	8.58
StOrb04	June 2018	19.5	1714	8	0.013	0.18	0.12	8.71	5.82	7.45
	July 2018	22.2	2223	7.16	0.012	0.13	0.91	9.65	6.13	7.4
	May 2019	18.5	2513	8.81	0.032	0.08	0.09	7.16	6.21	8.14
	June 2019	18.5	2597	8.81	0.032	0.07	0.1	8.03	6.93	8.58
StOrb05	June 2018	17.5	1705	8	0.042	0.07	0.63	10.37	4.18	7.51
	July 2018	21.1	2108	7.16	0.024	0.05	0.58	10.28	6.72	7.58
	May 2019	20.1	2763	9.02	0.009	0.01	0.73	9.88	6.83	8.15
	June 2019	20.1	2763	9.02	0.009	0.07	0.65	9.93	6.14	8.15
StOrb06	June 2018	19.7	1683	7.8	0.067	0.03	0.18	11.48	2.56	7.55
	July 2018	23.1	2230	7.98	0.049	0.01	0.34	8.93	3.16	7.81
	May 2019	22.3	2797	8.69	0.13	0.08	0.35	8.273	4.12	8.23
	June 2019	24.4	2959	7.14	0.127	0.03	0.28	8.1	5.36	8.12
StChbk02	June 2018	17.5	1179	7.6	0.042	0.06	0.07	7.87	4.36	7.51
	July 2018	22.7	1684	7.16	0.023	0.02	0.05	7.63	4.52	7.62
	May 2019	23.7	2597	7.48	0.008	0.1	0.08	9.13	3.88	8.04
	June 2019	23.8	2708	6.68	0.028	0.05	0.08	9.02	4.12	8.44

$$IBMR = \frac{\sum_i^n Ei \times Ki \times CSi}{\sum_i^n Ei \times Ki} \quad (1)$$

where: i – contributing species.

The IBMR results are interpreted using a color-coded grid corresponding to five water trophic levels (blue – very low; green – low; yellow – moderate; orange – high; red – very high). The IBMR index was calculated for sites that have at least two contributing species, so stations StFel, StChbk01, and StSru were omitted. The IBMR score and its robustness were calculated for the concerned sites (Table 2). Robustness recalculates IBMR by eliminating the taxon with the highest Ei × Ki value (stenoecy coefficient × coverage coefficient). If the difference between the IBMR score and its robustness is less than one, this suggests that the IBMR score is robust; if it is greater than one, it indicates that the score is influenced by some particular taxa Figure 2.

In order to verify and test the reliability of the IBMR index results, a Pearson correlation was carried out with the physicochemical parameters of the water, which are measured simultaneously at each site

RESULTS AND DISCUSSION

Watercourses constitute complicated systems of interactions between macrophytes' biological and ecological traits as well as the hydrochemical and morphological aspects of their environment. Any change in one of this ecosystem's compartments can have an impact on the functioning of the other compartments. In this regard, to assess the quality of running water, it is preferable to take into consideration, alongside physicochemical analyses of the water, the biological components, particularly macrophytes. In this context,

Table 2. IBMR score, robustness, and trophic level, with color assigned for each study site

Parameter			IBMR Score	Trophic level	Number of Contributing species	Contributing Species Coverage (%)	Species with highest (Ei x Ki) value	IBMR Robustness	Trophic level
Amengous river	StAmg01	June 2018	9.78	High	9 (23)	67.22	*Groenlandia densa*	9.45	High
		July 2018	9.77	High	8 (23)	69.96	*Groenlandia densa*	9.41	High
		May 2019	9.82	High	7 (23)	76.37	*Groenlandia densa*	9.46	High
		July 2019	9.95	High	9 (23)	86.46	*Groenlandia densa*	9.69	High
	StAmg02	June 2018	9.50	High	9 (23)	17.33	*Groenlandia densa*	9.15	High
		July 2018	9.89	High	9 (23)	23.19	*Myriophyllum spicatum*	10.43	Moderate
		May 2019	9.74	High	10 (23)	57.64	*Groenlandia densa*	9.44	High
		July 2019	9.80	High	10 (23)	67.33	*Groenlandia densa*	9.53	High
	StAmg03	June 2018	10.04	Moderate	6 (23)	26.23	*Veronica anagallis-aquatica*	9.74	High
		July 2018	10.10	Moderate	7 (23)	17.49	*Persicaria amphibia*	10.39	Moderate
		May 2019	9.75	High	9 (23)	11.83	*Groenlandia densa*	9.5	High
		July 2019	9.84	High	8 (23)	14.39	*Groenlandia densa*	9.58	High
	StAmg04	June 2018	9.50	High	6 (23)	6.73	*Groenlandia densa*	9	High
		July 2018	9.11	High	7 (23)	15.26	*Groenlandia densa*	8.57	High
		May 2019	9.30	High	8 (23)	16.05	*Groenlandia densa*	8.81	High
		July 2019	9.97	High	7 (23)	18.00	*Groenlandia densa*	9.7	High

Oum Er-rbia river	StOrb01	June 2018	11.23	Moderate	3 (23)	10.49	*Brachythecium rivulare*	8	Very High
		July 2018	10.36	Moderate	7 (23)	20.15	*Brachythecium rivulare*	8.89	High
		May 2019	9.65	High	8 (23)	16.60	*Brachythecium rivulare*	7.76	Very High
		July 2019	10.14	Moderate	9 (23)	17.95	*Diatoma* sp.	9.65	High
	StOrb02	June 2018	8.11	High	6 (23)	6.39	*Ulva* sp.	10.46	Moderate
		July 2018	9.89	High	9 (23)	23.19	*Ulva* sp.	10.43	Moderate
		May 2019	7.24	Very High	8 (23)	11.25	*Brachythecium rivulare*	5.52	Very High
		July 2019	7.24	Very High	8 (23)	11.28	*Brachythecium rivulare*	5.52	Very High
	StOrb03	June 2018	6.63	Very High	5 (23)	6.44	*Ulva* sp.	7.83	Very High
		July 2018	6.63	Very High	5 (23)	6.28	*Ulva* sp.	7.83	Very High
		May 2019	7.00	Very High	8 (23)	17.52	*Ulva* sp.	8.26	High
		July 2019	7.30	Very High	8 (23)	18.01	*Ulva* sp.	8.52	High
	StOrb04	June 2018	6.70	Very High	5 (23)	26.15	*Ulva* sp.	8.29	Very High
		July 2018	5.63	Very High	4 (23)	20.83	*Ulva* sp.	7.2	Very High
		May 2019	7.10	Very High	3 (23)	25.89	*Zannichellia palustris*	8.5	High
		July 2019	7.10	Very High	3 (23)	25.96	*Zannichellia palustris*	8.5	High
	StOrb05	June 2018	5.22	Very High	4 (23)	14.98	*Ulva* sp.	6.33	Very High
		July 2018	5.33	Very High	6 (23)	21.38	*Ulva* sp.	6.11	Very High
		May 2019	4.79	Very High	4 (23)	14.89	*Potamogeton pectinatus*	6.88	Very High
		July 2019	4.79	Very High	4 (23)	15.09	*Potamogeton pectinatus*	6.88	Very High
	StOrb06	June 2018	3.33	Very High	2 (23)	7.00	*Potamogeton pectinatus*	6	Very High
		July 2018	6.69	Very High	5 (23)	24.52	*Diatoma* sp.	4.33	Very High
		May 2019	7.54	Very High	3 (23)	5.04	*Diatoma* sp.	3.71	Very High
		July 2019	8.00	Very High	4 (23)	5.10	*Diatoma* sp.	5.33	Very High
Ichbouka river	StChbk02	June 2018	9.73	High	6 (23)	7.98	*Phragmites australis*	10	High
		July 2018	10.81	Moderate	8 (23)	13.53	*Diatoma* sp.	10.54	Moderate
		May 2019	9.45	High	6 (23)	23.41	*Diatoma* sp.	9.63	High
		July 2019	9.58	High	6 (23)	30.23	*Diatoma* sp.	9.78	High

an index approach (IBMR) based on macrophyte was applied. Among the inventoried species, 22 taxa contribute to the calculation of IBMR (Table 3). Hydrophytes are the most abundant, occupying 56.52% (13 taxa), helophytes and hygrophytes represent 30.43% (6 taxa) of all species. Bryophytes are represented by one moss species (4.34%), and bacteria are represented by two taxa (8.69%). It was noted that the contributing species constitute only 28% of all the inventoried species in the same sites between June 2018 and June 2019 (Nouri et al., 2022).

According to the IBMR scores, most of the Amengous river sites have a "high" trophic level, with the exception of StAmg03, which had a "moderate" trophic level in June and July 2018 with values of 10.04 and 10.1, respectively. The robustness assessed for the IBMR scores confirms its relevance during the four months for the StAmg01 and StAmg04 by remaining at the same trophic level with a difference less than 1. Although the robustness of the IBMR at StAmg02 shows some stability for the scores obtained, the recalculation of the IBMR in July 2018 made it possible to change the trophic level from "high" with a score of 9.89 to "moderate" with a score of 10.43. This can be explained by the elimination of *Myriophyllum spicatum* from the calculation, which corresponds to the most stenoecious and abundant contributing species in this month.

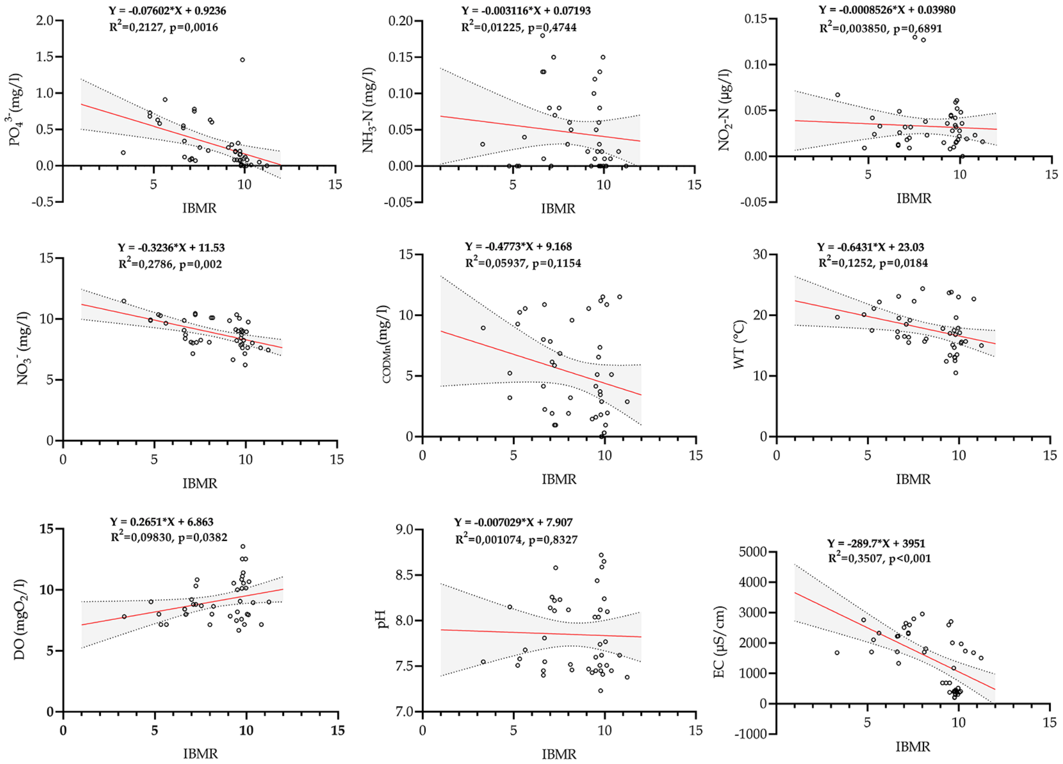

Figure 2. Scatterplots and fitted linear regression lines (with 95% confidence interval)

Table 3. List of contributing species inventoried in the study sites, each with its ecological amplitude and trophic affinity values (based on the NF T90-395 standard)

Taxonomic group	Species	Life form	Species' trophic tendencies	Species' ecological amplitude
Phanerogams	*Agrostis stolonifera L.*	Emerged	10	1
	Eleocharis palustris (L.) Roem.& Schult.	Emerged	12	2
	Groenlandia densa (L.) Fourr.	Submerged	11	2
	Helosciadium nodiflorum (L.) W.D.J. Koch.	Emerged	10	1
	Myriophyllum spicatum L.	Submerged	8	2
	Nasturtium officinale R.Br.	Emerged	11	1
	Persicaria amphibia (L.) Gray.	Submerged	9	2
	Phragmites australis (Cav.) Trin. Ex Steud.	Emerged	9	2
	Ranunculus aquatilis L.	Submerged	11	2
	Stuckenia pectinata (L.) Börner.	Submerged	2	2
	Typha angustifolia L.	Emerged	6	2
	Typha latifolia L.	Emerged	8	1
	Veronica anagallis-aquatica L.	Emerged	11	2
	Zannichellia palustris L.	Submerged	5	1
Algae	*Chara vulgaris Linnaeus.*	Submerged	13	1
	Cladophora sp.	Submerged	6	1
	Diatoma sp.	Submerged	12	2
	Spirogyra sp.	Submerged	10	1
	Vaucheria sp.	Submerged	4	1
Bacteria	*Nostoc sp.*	Submerged	9	1
	Sphaerotilus natans Kützing,	Submerged	0	3
Bryophyte	*Brachythecium rivulare Schimp.*	Submerged	15	2

The robustness of the IBMR score at StAmg03 reveals some stability (difference less than 1), but with a downgrading of the trophic level in June 2018 from “moderate” with a score of 10.04 to “high” with a score of 9.74. This result may be due to the effect of *Cladophora* sp. (euryecium and abundant) on the calculation of IBMR after the elimination of *Veronica anagallis-aquatica*, which had more weight (stenoecy and abundant) compared to all contributing taxa in StAmg03.

During the four months, the IBMR scores calculated for Oum Er-rbia river sites tend to decrease downstream, reflecting a trophic level ranging from “moderate” to “very high.” StOrb01 has a “moderate” trophic level with the exception of May 2019, when IBMR shows a high trophic level with a score of 9.65. The IBMR score at StOrb02 in June and July 2018 shows a “high” trophic level, which was decreased to a “very high” level in May and June 2019. The sites StOrb03, StOrb04, StOrb05, and StOrb06 present a “very high” trophic level for all months, with a minimum value of 3.33 in June 2018 in StOrb06.

The robustness of the IBMR scores for various Oum Er-rbia river sites indicates that this metric cannot be considered relevant (difference significantly greater than 1). The low values of IBMR and its instability can be explained by a low richness in contributing species (Demars et al., 2012; Maissour and Benamar 2019). Thus, the Oum Er-rbia river is characterized by the dominance of algal flora, notably *Spirogyra* sp., *Vaucheria* sp., and *Cladophora* sp., which are considered ubiquitous taxa (Nouri et al., 2022), they can grow to the detriment of sensitive species and directly affect the IBMR score (Treguier and Lietout 2019). In three months (June 2018, May, and June 2019), the StChbk02 site shows a “high” trophic level. In July 2018, water quality improved with a score of 10.81, indicating a “moderate” trophic level. The robustness evaluated for the IBMR scores confirms its relevance during the four months for this site, which reflects the homogeneity of the floristic communities (DREAL-Languedoc Roussillon 2011).

The Pearson correlation between the physicochemical parameters and the IBMR scores (Table 4) revealed a significant negative correlation with orthophosphate (PO_4^{3-}), nitrate (NO_3^-), water temperature (WT), and electrical conductivity (EC) and a significant positive correlation with dissolved oxygen.

Although IBMR shows a negative correlation with other elements such as oxidizable organic matter (COD_{Mn}), nitrite nitrogen (NO_2-N), and ammoniacal nitrogen (NH_3-N), it remains insignificant. The Pearson test results appear encouraging, particularly for orthophosphates and nitrates, which are frequently considered trophic level regulators in aquatic environments (Baláži et al., 2014; Terneus-Jácome et al., 2020; Thiébaut 1997). However, the graphical presentation of the scatterplots between the IBMR scores and the physicochemical parameters reveals that IBMR can categorize a site as having a “high” trophic level even in the presence of low orthophosphate concentrations (Fig. 2). This result is consistent with the findings of another study on the use of IBMR to assess the trophic state of rivers in Italy (Fabris 2010).

Although the IBMR scores reveal that the trophic state of the sectors studied oscillates between “moderate” and “very high”, the physicochemical parameters measured for the same sectors show that the water quality varies from “moderate” to “excellent” (Decree n° 1275-01). Thus, the determination of a high trophic level by the IBMR index does not necessarily reflect the deterioration of the quality of the aquatic environment (Rodier 2009).

The water quality of this sort of hydrosystem depends on the interaction of several factors, including flow velocity, luminosity, depth, type of substrate, etc. Water is naturally rich in nutrients (the strict meaning of eutrophication) and promotes the growth of macrophytes without being damaged by artificial nutrient inputs. The disparity between the water quality levels according to the Moroccan standard and the trophic levels proposed by the IBMR index can be explained by the effect of the downgrading physico-chemical parameter “one out/all out” (Bouleau and Pont 2014).

Taking the Amengous river in July 2018 as an example: the IBMR score obtained for the StAmg02 is 9.89, indicating a “high” trophic level, and the values of the physico-chemical

Table 4. Pearson correlation between IBMR scores and physicochemical parameters

Score	PO_4^{3-}	NH_3-N	NO_3^-	NO_2-N	COD_{Mn}	WT	DO	pH	EC
IBMR score	-0,461**	-0,111	-0,528**	-0,062	-0,244	-0,354*	0,314*	-0,033	-0,592**

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

parameters exhibiting a significant correlation with the IBMR index are: PO_4^{3-} (1,46 mg/l), NO_3^- (8,26 mg/l), WT (13,5 °C), $O_{2Dissolved}$ (7,16 mgO_2/l) and EC (374 µs/cm). With the exception of orthophosphates (Table 1), these parameters indicate excellent water quality in accordance with the Moroccan surface water quality standard (Decree n° 1275-01). However, the IBMR score indicates a "high" trophic level, which can be explained by the concept parameter downgrading "one out/all out", which corresponds in this case to orthophosphates.

CONCLUSIONS

IBMR can be considered a tool that provides an overall assessment of a river's trophic state. This assessment is only reliable under well-defined conditions, such as stable hydrological conditions with a richness in contributing sensitive pollution species. Its implementation in the rivers studied revealed some limitations, such as ubiquitous species and the one-out, all-out rule, that necessitate further investigation, particularly the autoecology of native aquatic plants and the physicochemical characterization of the water. As a result, further research on macrophytes in Moroccan hydrosystems is required in order to establish a national metric for Moroccan rivers.

REFERENCES

1. Baláži, P., Hrivnák, R., Ot'Ahelová, H. 2014. The relationship between macrophyte assemblages and selected environmental variables in reservoirs of Slovakia examined for the purpose of ecological assessment. Polish Journal of Ecology, 62(3), 541–558. https://doi.org/10.3161/104.062.0313
2. Bentaibi, S., Rahou, A., Chillasse, L., Hammada, S., Abba, E. 2017. Evaluation of biological water quality by biological macrophytic index in river: application on the watershed of Beht River. European Scientific Journal, ESJ, 13(27), 217. https://doi.org/10.19044/esj.2017.v13n27p217
3. Bouleau, G., Pont, D. 2014. Les conditions de référence de la directive cadre européenne sur l'eau face à la dynamique des hydrosystèmes et des usages. Natures Sciences Societes, 22(1), 3–14. https://doi.org/10.1051/nss/2014016
4. Demars, B.O.L., Potts, J.M., Trémolières, M., Thiébaut, G., Gougelin, N., Nordmann, V. 2012. River macrophyte indices: Not the Holy Grail! Freshwater Biology, 57(8), 1745–1759. https://doi.org/10.1111/j.1365-2427.2012.02834.x
5. Dreal-Languedoc Roussillon. 2011. Realisation De Prelevements Et Determination Des Listes Et Indices Biologiques - Indices "Macrophytes – Ibmr".
6. Dutartre, A., Haury, J., Peltre, M.C., Alain Dutartre, Jacques Haury, Marie-Christine Peltre. 2008. Plantes aquatiques d'eau douce : biologie, écologie et gestion. Cemagref HS Revue Ingénierie Eau-Agriculture-Territoire, 161. https://books.google.at/books/about/Plantes_aquatiques_d_eau_douce_biologie.html?id=16R4BvZK1HAC&redir_esc=y
7. Fabris, M. 2010. The macrophyte vegetation of running waters in the North-East of Italy: a study of the influence of morphological variables and chemical parameters on the aquatic plant community.
8. Flor-Arnau, Núria, Real, Montserrat, González, Gloria, Cambra Sánchez, Jaume, Moreno, José Luis, Solà, Carolina, Munné, Antoni. 2015. Índice de Macrófitos Fluviales (IMF), una nueva herramienta para evaluar el estado ecológico de los ríos mediterráneos. Limnetica, 34(34), 95–114. https://doi.org/10.23818/limn.34.09
9. Haury, J., Peltre, M.C., Muller, S., Thiebaut, G., Tremolières, M., Demars, B., Barbe, J., Dutartre, A., Daniel, H., Bernez, I., Guerlesquin, M., Lambert, E. 2001. Les macrophytes aquatiques bioindicateurs des systèmes lotiques. Intérêts et limites des indices macrophytiques. Synthèse bibliographique des principales approches européennes pour le diagnostic biologique des cours d'eau. UMR INRA-ENSA EQHC Rennes & Phytoecologie Univ. Metz. Agence de l'Eau Artois-Picardie, Etudes Sur l'Eau En France, 87, 101 + ann.
10. Haury, J., Peltre, M.C., Trémolières, M., Barbe, J., Thiébaut, G., Bernez, I., Daniel, H., Chatenet, P., Haan-Archipof, G., Muller, S., Dutartre, A., Laplace-Treyture, C., Cazaubon, A., Lambert-Servien, E. 2006. A new method to assess water trophy and organic pollution – The Macrophyte Biological Index for Rivers (IBMR): Its application to different types of river and pollution. Hydrobiologia, 570(1), 153–158. https://doi.org/10.1007/s10750-006-0175-3
11. Holmes, N., Newman, J., Chadd, S., Rouen, K., Saint, L., Dawson, F. 1999. Mean Trophic Rank : A User's Manual R&D Technical Report E38. In Bristol, UK (p. 156). http://www.epa.ie/wfdstatus/RIVERS/RW_MTR_Methods_Manual.pdf
12. Maissour, A., Benamar, S. 2019. Impact of hydromorphological pressures on the macrophytes bioindicators of the ecological water quality in mediterranean rivers. BioRisk, 14, 1–14. https://doi.org/10.3897/biorisk.14.30319
13. Nouri, A., Hammada, S., Chillasse, L. 2022. Exploring factors driving macrophytes in rivers—A

case study in Middle Atlas Morocco. Ecohydrology, April, 1–15. https://doi.org/10.1002/eco.2506

14. Nouri, A., Soumaya, H., Lahcen, C., Abdelmajid, H. 2021. Macrophytes as a tool for assessing the trophic status of a river: A case study of the upper Oum Er Rbia Basin (Morocco). Oceanological and Hydrobiological Studies, 50(1), 77–86. https://doi.org/10.2478/oandhs-2021-0008
15. Pieterse, A., Rytkönen, M., Hellsten, S. 2009. Aquatic weeds. Proceedings of the 12rd European Weed Research Society Symposium, August 24-28.2009, Jyväskylä, Finland. Finnish Environment Institute.
16. Rodier, J. 2009. L'analyse de l'eau. International Journal of Biological and Chemical Sciences, 1(1), 1579.
17. Schneider, S., Melzer, A. 2003. The Trophic Index of Macrophytes (TIM) - A new tool for indicating the trophic state of running waters. International Review of Hydrobiology, 88(1), 49–67. https://doi.org/10.1002/iroh.200390005
18. Szoszkiewicz, K., Jusik, S., Pietruczuk, K., Gebler, D. 2020. The macrophyte index for rivers (MIR) as an advantageous approach to running water assessment in local geographical conditions. Water, 12(1). https://doi.org/10.3390/w12010108
19. Terneus-Jácome, E., Vallejo-Solano, B., Gómez de la Torre, M., Larenas-Uría, C. 2020. Trophic status index of lentic systems from the diversity of aquatic plants from continental Ecuador. Caldasia, 42(1), 115–128. https://doi.org/10.15446/caldasia.v42n1.77638
20. Thiébaut, G. 1997. Effets des perturbations liées à l'eutrophisation et l'acidification des cours d'eau des Vosges du nord sur les phytocénoses aquatiques : approche spatio-temporelle et expérimentale. Université Paul Verlaine-Metz.
21. Pedro T., Moreno L.J., Aboal M., Oscoz J., Durán C., Navarro P. 2016. Evaluación del estado ecológico de los ríos de la cuenca del río Ebro mediante el índice trófico de macrófitos IVAM-G (Índice de Vegetación Acuática Macroscópica). Limnetica, 35(35), 219–234. https://doi.org/10.23818/limn.35.18
22. Treguier, M., Lietout, M. 2019. Suivi des macrophytes des plans d'eau du bassin Artois-Picardie.
23. Wiederkehr, J. 2015. Estimation des incertitudes associées aux indices macroinvertébrés et macrophytes pour l'évaluation de l'état écologique des cours d'eau.