

From Index to Decision: A Critical Review of Water Quality Indices Applied to Moroccan Waters (2018–2025)

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Abstract. Water Quality Indices (WQIs) are widely used to synthesize information on water quality and support decision-making. In Morocco, their application has grown significantly in recent years for the assessment of surface and groundwater. However, the diversity of indices, parameters used, weighting schemes, and reporting practices limits the comparability and robustness of results. This study offers a critical analysis of the applications of WQIs to Moroccan waters over the period 2018–2025, based on a systematic review of 244 articles indexed in Scopus. The results highlight significant methodological heterogeneity, notable classification differences for comparable contexts, and a lack of transparency regarding the management of missing data and uncertainties. In order to strengthen the scientific and decision-making value of WQIs, a minimal harmonization framework adapted to the semi-arid Moroccan context is proposed, based on a common set of parameters, explicit data processing rules, double reading by reference indices, and standardized reporting.

Keywords. Water Quality Index (WQI); Morocco; Methodological harmonization; Decision support.

1 Introduction

In Morocco, assessing water quality has become a major scientific challenge, against a backdrop of climate pressure, urban growth, agricultural intensification, and increased domestic and industrial waste [1-5]. In this context, Water Quality Indices (WQIs) have established themselves as a widely used summary tool in the literature, as they allow a set of physicochemical and/or microbiological parameters to be condensed into a single value and an easily interpretable quality class [6-9]. This simplification facilitates the communication of results, spatiotemporal comparison within a watershed, and rapid identification of areas at risk. Between 2018 and 2025, their use has become particularly widespread in academic studies focusing on both surface water (rivers, reservoirs, lakes) and groundwater (aquifers), often in support of spatial and cartographic analyses [10-12].

However, this popularity comes with a key methodological limitation: limited comparability between studies. Published studies use a variety of indices (e.g., NSFQI, CCME-WQI, OWQI/ORWQI, IRWQI, and various adaptations), based on different calculation methods (normalization, aggregation, penalty for exceedances, etc.). At the same time, the selection of parameters differs greatly from one study to another, both in number and type, depending on data availability, the environment studied, and the pressures targeted (salinity, nutrients, organic load, metal contamination, fecal contamination). Weighting

schemes, when used, are not uniform and can significantly alter the relative contribution of parameters to the final score [11, 13-15]. Thus, the same site or type of environment may be classified differently depending on the index chosen, the list of parameters selected, and the weightings applied, which limits reproducibility and complicates interregional or inter-study comparisons, particularly when the results are discussed in terms of management decisions [2, 16, 17].

In this context, this paper offers a critical analysis of WQIs applied to Moroccan waters over the period 2018–2025, covering both surface water and groundwater. The objective is (i) to map the dominant methodological practices in recent literature (types of indices, parameters, weightings, normalization and classification methods), (ii) to identify the main sources of divergence that may affect the comparability and robustness of the results, and (iii) to develop recommendations for minimum harmonization, particularly in terms of transparency of methodological choices and standardization of reporting. Based on these objectives, three questions guide the study: Which indices and sets of parameters are most frequently used in Morocco between 2018 and 2025? To what extent do differences in parameter selection, weighting, and calculation schemes lead to classification discrepancies for comparable contexts? Finally, what practical standardization measures can be proposed to enhance the scientific and decision-making value of WQIs in future research on Moroccan waters?

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2 Review methodology

A systematic literature review was conducted in the Scopus database, chosen for its broad coverage of peer-reviewed international journals. The search explicitly targeted publications using a Water Quality Index (WQI) in the Moroccan context, via a query on the Title, Abstract, and Keywords fields in order to capture both studies focused on the WQI (in the title) and those where the index is used as a methodological tool (mentioned in the abstract or keywords). The main keywords were "Water Quality Index" and "Morocco," in line with the objective of covering WQI applications to Moroccan waters in the recent period.

The time frame was set at 2018–2025 in order to analyze recent practices and how they have evolved. The following were included: (i) articles dealing with surface water and/or groundwater in Morocco, (ii) works published in English, (iii) documents at the "final" stage, and (iv) research articles (DOCTYPE = ar). The following were excluded: non-article documents (reviews, notes, conferences, chapters, etc., according to the Scopus configuration), works outside the period, non-final publications, studies not relating to Morocco, and those not actually using a WQI (superficial mention without calculation, ranking, or clear protocol). The Scopus query applied is as follows: *TITLE-ABS-KEY (Water QUALITY INDEX Morocco) AND (LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024) OR LIMIT-TO (PUBYEAR , 2025)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (LANGUAGE , "English"))*.

For each article selected, an extraction grid was used to ensure consistency in data collection and comparability. The variables extracted include: (i) the type of index (NSFWQI, CCME-WQI, OWQI/ORWQI, IRWQI, or variant), (ii) the environment studied (surface, groundwater, or mixed), and, when available, the type of matrix (rivers, reservoirs, aquifers, etc.), (iii) the list of parameters considered and their number (physicochemical, nutrients, microbiology, metals), (iv) the presence and logic of weighting (weight, justification, normalization), (v) consideration of seasonality (multi-season campaigns, wet/dry periods), and (vi) the final quality class (and associated classification grid). Missing or ambiguous information (e.g., weightings not reported) was noted as such in order to be discussed as a methodological result in its own right.

The analysis was based on a descriptive and comparative approach. First, the studies were grouped by type of WQI and by environment (surface vs. groundwater) to identify usage typologies (dominant parameters, weighting practices, quality classes). Next, a critical synthesis was conducted to identify the major sources of non-comparability, including: heterogeneity of parameter sets, differences in normalization / aggregation functions, diversity of weightings, and variations in thresholds or classification grids. Finally,

methodological convergences and divergences were discussed in terms of their impact on interpretation (risk of class change depending on the index/parameters) and on the ability of WQIs to support a robust reading "from index to decision."

3 Results: mapping of WQI practices in Morocco (2018–2025)

3.1 Most commonly used indices (NSFWQI, CCME-WQI, OWQI/ORWQI, IRWQI, variants)

The first observation is an important bibliometric signal in itself: more than half of the articles do not explicitly mention the type of WQI in their metadata. This "under-reporting" makes inter-study comparison difficult from the identification stage onwards. Among the studies where the index is identifiable by name, CCME-WQI is the most visible index. Occurrences of NSFWQI, OWQI/ORWQI, and weighted arithmetic approaches are present but remain marginal in abstracts/keywords. Finally, several articles mention related indices (e.g., HPI, etc.) that sometimes serve as substitutes or complements to the classic WQI in the quality argument.

Table 1. Types of indices mentioned in the metadata (n = 244)

Detected type (metadata-based)	n	%
No explicit WQI term	138	56.6
Generic WQI (unspecified index)	62	25.4
Other named indices (e.g., HPI, etc.)	34	13.9
CCME-WQI	6	2.5
Weighted arithmetic WQI	3	1.2
NSFWQI	3	1.2
OWQI/ORWQI	1	0.4

3.2 Environments studied (rivers, dams/lakes, groundwater, coastal areas)

The studies are dominated by groundwater (aquifers / wells), followed by rivers/wadi and coastal/estuarine environments. Dams / reservoirs / lakes appear less frequently in the metadata. Note: several articles also focus on drinking water/supply (which often overlaps with groundwater and/or collected surface water).

Table 2. Top parameters mentioned in metadata

Parameter (mention-based)	n	%
pH	61	25.0
Heavy metals (generic term)	53	21.7
Electrical conductivity (EC)	52	21.3
Lead (Pb)	48	19.7
Nitrate (NO ₃ ⁻)	45	18.4
Cadmium (Cd)	40	16.4

Salinity	40	16.4
Dissolved oxygen (DO)	33	13.5
Chromium (Cr)	33	13.5
Iron (Fe)	28	11.5
Chloride (Cl ⁻)	28	11.5
Sulfate (SO ₄ ²⁻)	27	11.1
COD (chemical oxygen demand)	20	8.2
Coliforms / E. coli	20	8.2
Ammonium (NH ₄ ⁺)	19	7.8

3.3 Parameters: heterogeneity of lists (pH, DO, EC/TDS, turbidity, BOD₅, NO₃⁻, PO₄³⁻, metals, coliforms, etc.)

The mapping of parameters reveals an organization in successive layers, ranging from a basic physicochemical foundation (pH, electrical conductivity, dissolved oxygen) to components related to mineralization (salinity, chlorides, sulfates, TDS), nutrients (NO₃⁻, NH₄⁺, PO₄³⁻) and, significantly, metal contamination (Pb, Cd, Cr, Fe, Mn). Microbiological indicators (coliforms, E. coli) are integrated on a more ad hoc basis. The strong presence of metals in WQI studies suggests either an expansion of the indices beyond the traditional schemes or a combined use of the WQI with specific metal pollution indices, accentuating the methodological heterogeneity between studies.

Table 3. Top parameters mentioned in metadata (n = 244)

Parameter (mention-based)	n	%
pH	61	25.0
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Ammonium (NH ₄ ⁺)	19	7.8

3.4 Weightings and standardization: what are the rationales and differences?

On the issue of weightings/standardization, the metadata mainly reveal structural opacity: around two-thirds of

articles do not clearly indicate these elements in the abstract / keywords. When mentioned, references to standards/limits/guidelines (WHO, etc.) appear more often than explicit descriptions of weighting. This suggests a practice where the "standard" is emphasized more than the mathematical architecture of the index.

Table 4. Weighting / normalization signals in metadata (n = 244)

Methodological signal (mention-based)	n	%
Not specified in metadata	165	67.6
Standards/limits/guidelines referenced	47	19.3
Weights/weighting mentioned	29	11.9
CCME elements (F1/F2/F3 logic) mentioned	6	2.5
Sub-index / rating / normalization mentioned	5	2.0
Weighted arithmetic method mentioned	3	1.2

3.5 Season/temporal variability: what is taken into account (or not)

Seasonality appears to be another weak point: only about a quarter of the articles explicitly mention a temporal / seasonal design in the metadata, and an even smaller fraction explicitly mention a wet vs. dry contrast.

Table 5. Seasonality/temporal design signals in metadata (n = 244)

Seasonality signal (mention-based)	n	%
Not specified in metadata	181	74.2
Explicit seasonal/temporal design	59	24.2
Wet vs dry comparison	17	7.0

3.6 WQI–GIS coupling: “decision-making” trends

WQI–GIS coupling is present in approximately one in four articles via mapping/spatialization signals. However, explicitly cited interpolation methods (IDW/Kriging) and remote sensing remain in the minority in the metadata.

Table 6. WQI–GIS coupling signals in metadata (n = 244)

GIS coupling signal (mention-based)	n	%
No GIS signal in metadata	180	73.8
GIS / mapping / spatial distribution mentioned	61	25.0
Remote sensing mentioned	10	4.1
Spatial interpolation (IDW/Kriging) mentioned	7	2.9

4 Critical discussion

A key finding of the review is that WQIs do not simply produce a "score"; they produce an interpretation, and this interpretation depends heavily on the index chosen. Two studies evaluating the same site (or comparable sites) may result in a difference of one or two quality classes simply because the calculation architecture is not the same. Weighted arithmetic indices aggregate sub-scores (often weighted) and tend to smooth out extremes: highly degraded parameters can be "diluted" by satisfactory parameters, especially if the weighting is not explicitly justified. Conversely, the CCME-WQI is based on a logic of compliance with standards, integrating the frequency and amplitude of exceedances (penalizing logic), which can significantly lower the score when a small number of parameters regularly exceed the limits. Thus, a site with high mineralization (EC/salinity) or nitrates close to the thresholds may be classified as "average" with one index and "poor" with another, especially when the reference thresholds differ (drinking water standards vs. environmental standards vs. local criteria).

These differences are accentuated by (i) the selection of parameters (minimal set vs. enriched set with metals and microbiology), (ii) weightings (equivalent weights vs. expert weights), and (iii) classification grids (number of classes, cut-off thresholds, terminology). In other words, non-comparability is not a technical detail: it can lead to contradictory interpretations of the priority for action (site to be monitored vs. site to be remediated), and therefore to a different trajectory "from index to decision." To avoid this, a minimum requirement for transparency should be systematic: specify the exact name of the WQI, the parameters included, the thresholds used, and the aggregation logic, ideally in the summary or at least in a standard methodology box.

Most WQI applications rely on sampling campaigns where data may be incomplete, heterogeneous (different frequencies depending on parameters), or affected by analytical limitations (LOD/LOQ, censored values, outliers). However, how to deal with these problems is rarely documented in detail, even though it can change the final class. Missing data is particularly critical when the missing parameters are those that drive the index (e.g., microbiology or metals): omitting these parameters often results in an "optimistic" WQI that reflects basic chemistry rather than health or toxic risks.

In addition, WQIs combine measurements that each have an uncertainty (field measurement, laboratory measurement, transport/storage). In theory, uncertainty in each parameter is propagated to the final score, but in practice this propagation is rarely quantified. Without uncertainty estimation, two WQI values close to a class threshold may be misinterpreted as two different states (e.g., "good" vs. "medium"), even though they are statistically indistinguishable. This creates a bias of over-interpretation, amplified when authors compare seasons (wet/dry) or areas (upstream/downstream) without assessing the robustness of the differences.

A strong methodological recommendation is therefore to incorporate, even in a simple way, an uncertainty assessment: (i) reporting missing data and how it has been handled, (ii) sensitivity tests (which parameters dominate the score), (iii) robustness

scenarios (e.g., WQI recalculated with/without a key parameter), or (iv) Monte Carlo-type approaches when the data allow. The aim is not to increase complexity, but to avoid the index becoming an "exact number" when it summarizes uncertain measurements.

WQIs are very effective in providing an integrated reading of water quality, especially when the objective is (i) communication, (ii) spatial-temporal comparison, or (iii) prioritization of areas to be monitored. They effectively summarize "classic" issues when captured by the parameters included: mineralization, organic load (BOD/COD), nutrients, and sometimes fecal contamination. They also provide a common language for transforming series of measurements into operational and mappable categories.

However, their power of synthesis is also their limitation. First, aggregation into a single score can mask critical signals: a highly degraded parameter (e.g., high nitrate, toxic metal, fecal contamination) can be drowned out in an overall correct set, especially in weighted average indices. Second, WQIs do not adequately capture cocktail effects: moderate concentrations of several pollutants can generate a greater ecological or health risk than a "parameter-by-parameter" reading, without the index reflecting this. Finally, standard WQIs are rarely designed to include emerging contaminants (pharmaceutical residues, modern pesticides, microplastics, PFAS, etc.) due to a lack of routine data and consolidated standards. As a result, a site may have a "good" WQI while presenting risks not covered by the index.

From an "Index to Decision" perspective, this means that the WQI should be considered a screening tool rather than a final verdict. Best practice is to accompany the score with (i) a table of critical parameters responsible for degradation, (ii) targeted complementary indicators (metals, microbiology, health risks), and (iii) an explicit discussion of what is not measured. This approach preserves the WQI's power of synthesis while reducing the risk of a decision based on an incomplete indicator.

5 Towards a harmonization framework adapted to Morocco's semi-arid context

In a semi-arid context such as Morocco, where hydrological variability (wet/dry seasons, extreme events, evaporation concentration) strongly influences quality parameters, the use of WQIs can only gain scientific and decision-making value through minimal harmonization of practices. The aim is not to impose a single index, but to make studies comparable, reproducible, and interpretable on an interregional and interannual scale. A pragmatic harmonization framework can be structured around four pillars: a minimum set of parameters, explicit data processing rules, a dual methodological approach using two reference indices, and standardized reporting.

First, defining a minimum set of parameters, aligned with national standards and practices (drinking water, irrigation, receiving environment), is a basic requirement for comparing results. This minimum set

should cover general chemistry (pH, temperature, conductivity/EC or TDS), oxygenation (DO for surface water), nutrients (at least NO_3^- and NH_4^+ , and PO_4^{3-} where relevant), as well as indicators of organic pressure (COD and/or BOD_5 for surface water and areas affected by discharges). In areas at risk to health, a microbiological indicator (coliforms or *E. coli*) should be included systematically. Finally, given the strong signal observed in recent Moroccan literature, a "metals" module can be integrated as a minimum core (e.g., Pb, Cd, Cr, Fe/Mn depending on the geogenic and anthropogenic context), or treated as a complementary block clearly separated from the basic WQI. The central idea is to avoid calculating a "WQI" on sets that are so different that they no longer describe the same environmental reality.

Secondly, harmonization requires explicit rules for managing missing values, as this is one of the main sources of bias and incomparability. Studies should report the rate of missing data per parameter and per site, specify the treatment applied (exclusion of the parameter, imputation, LOD/2 substitution, etc.) and justify this choice. A simple and robust rule is to define a minimum completeness threshold for calculating a WQI (e.g., a minimum percentage of available parameters) and to prohibit calculation when "critical" parameters are missing (e.g., microbiology in a health context, or nitrates in an agricultural context). The WQI calculation should also clearly indicate whether the value comes from a single campaign, a seasonal average, or a multi-year average, as these options do not have the same meaning or stability. In practice, these rules can be presented in the form of a short, reproducible protocol, which immediately increases the transparency of studies.

A third useful tool is the implementation of a systematic comparison between the NSFQI and the CCME-WQI, designed as a "double reading" rather than a competition between indices. The NSFQI (or comparable sub-indexes) provides an integrative reading often used for communication and comparison, while the CCME-WQI provides a compliance-focused reading that is sensitive to the frequency and magnitude of exceedances. Applying both to the same minimal set of parameters and the same thresholds makes it possible to quickly detect situations where "averaging" aggregation masks recurring exceedances, or, conversely, where a CCME-type penalty amplifies the effect of a few parameters. This dual reading is particularly relevant in Morocco, where water may be generally "acceptable" but occasionally constrained by salinity, nitrates, or microbiological exceedances. Scientifically, it provides cross-checking; in terms of decision-making, it clarifies the type of risk: diffuse degradation vs. targeted non-compliance.

Finally, the impact of harmonization depends heavily on standardized reporting. Each study should systematically provide a minimum amount of information: the final class and numerical value of the WQI, the sampling period (dates, season, frequency), the environment (surface/groundwater and type), the exact list of parameters included, the reference thresholds used (and their source), the

normalization/aggregation method, and the weightings where applicable. It is also good practice to include an uncertainty or robustness indicator: for example, a sensitivity analysis indicating which parameters dominate the score, or a confidence interval/rating when data completeness is limited. This reporting can be summarized in a one-page "WQI sheet" table, facilitating reproducibility and enabling future meta-analyses at the national level.

In summary, a harmonization framework adapted to Morocco's semi-arid context is based on "sufficient" rather than total standardization: a minimum common set of rules, transparent data processing rules, double reading by two reference indices, and structured reporting. This approach maintains the flexibility necessary for different environments and objectives, while radically improving the comparability of results and their translation into management decisions.

6 Conclusion

This study provides a critical overview of the applications of Water Quality Indices (WQIs) to Moroccan waters over the period 2018–2025, covering both surface water and groundwater. The results show that, although WQIs have established themselves as key tools for summarizing complex data and facilitating scientific and technical communication, their comparative and decision-making value remains heavily influenced by the underlying methodological choices. The differences observed between indices, the variability of the parameters used, the heterogeneity of the weightings, and the uneven consideration of seasonality can lead to significant classification discrepancies for similar hydrological contexts. In this context, the WQI should not be interpreted as an absolute verdict, but as a synthetic indicator whose relevance depends on transparency, reproducibility, and suitability to the context under study.

For the scientific community, these findings highlight the need to improve comparability between studies through more rigorous and systematic methodological reporting. The reproducibility of results requires clarification of the choices made regarding the index used, the parameters included, the reference thresholds, the normalization methods, and the weightings. For water resource managers, the WQI remains an effective tool for screening and spatial and temporal monitoring, provided that it is accompanied by a detailed reading of the critical parameters responsible for degradation. As for decision-makers, the use of WQI classes and their mapping as a support for territorial prioritization can only be fully relevant if the results are based on comparable methodological bases, otherwise differences in the index may be confused with real environmental differences.

At the operational level, this study highlights the value of a minimal harmonization framework adapted to Morocco's semi-arid context, aimed at enhancing the comparability, reproducibility, and actionability of WQIs. Such a framework is based on the definition of a minimum set of common parameters, supplemented in a

context-specific manner, on explicit rules for managing missing data and censored values, and on a dual interpretation of results using reference indices with complementary logics. Added to this is the need for standardized reporting, incorporating not only the WQI class and value, but also the sampling period, the parameters and thresholds used, the calculation methods and, where possible, a simple robustness indicator. By combining these elements, the WQI can fully play its role as an interface between scientific data and public decision-making, supporting more transparent, comparable, and scientifically based management choices.

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