

Contrasting hydrochemical conditions and temporal variability at three monitoring sites along the Sebou River, Morocco

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ABSTRACT

Hydrochemical monitoring at geographically identified locations provides a basis for interpreting river-water variability and selecting complementary indicators. Eighteen site-campaign records from the Sebou River in Morocco during 2024–2025 were analysed: twelve at Fès and three each at Kariat Ba Mohamed and M'Kannsa. Sixteen physicochemical indicators were summarised using site-specific statistics, three shared-date comparisons between Kariat Ba Mohamed and M'Kannsa, a spring–autumn sensitivity assessment at Fès and six exploratory within-site rank associations. Mean conductivity was 1062, 1580 and 1577 $\mu\text{S}/\text{cm}$, respectively; mean permanganate oxidizability was 2.25, 5.87 and 6.50 $\text{mg O}_2/\text{L}$. All recorded conductivity, chloride, sulfate and oxidizability values at Kariat Ba Mohamed and M'Kannsa exceeded the observed Fès maxima, including its spring–autumn subset. Shared-date comparisons revealed consistently higher chloride at M'Kannsa, while conductivity and oxidizability rankings changed among campaigns. At Fès, conductivity and chloride had coefficients of variation of 4.1% and 4.6%, compared with 36.5% for turbidity. None of the six rank associations met the Holm-adjusted significance criterion. The contribution is a traceable campaign-level archive that distinguishes stable ionic signals from more variable optical and oxidizable-matter indicators. The findings describe the included campaigns; asynchronous and unequal coverage does not support an independent geographical effect or causal pollution-source attribution.

Keywords: Sebou River, hydrochemistry, environmental monitoring, water-quality variability, unequal sampling, Morocco.

INTRODUCTION

River-water chemistry integrates geochemical conditions, hydrological transport and human pressures. Pollution, altered flows and sediment disturbance can interact within large river systems (Best, 2019), alongside wider threats to freshwater biodiversity (Reid et al., 2019). Major solutes provide information on ionic composition and its change (Wu et al., 2021), while optical turbidity, oxygen conditions, nutrients and metals describe other aspects of water quality. A monitoring assessment should therefore consider the information added by different indicator groups rather than relying on one constituent.

In the Sebou basin, multi-location investigations have documented nutrient and metal pollution in reaches influenced by urban and industrial inputs (Perrin et al., 2014). Hayzoun et al. (2015) examined organic carbon and dissolved and particulate element dynamics. Experimental work on Sebou sediments shows that physicochemical conditions influence metal retention and release (Hassimi et al., 2019), and basin sediment studies document metal concentrations (Dra et al., 2019; El Hajjami et al., 2021). Chedadi et al. (2023) evaluated physicochemical and bacteriological quality along a tributary of the Sebou. These studies establish regional context, but differences in reaches, hydrology, analytical fractions and

sampling periods limit direct numerical comparisons with a new monitoring record.

Environmental interpretation also depends on when and how often samples are collected. Natural and anthropogenic drivers can affect constituents differently (Anh et al., 2023), and hydroclimatic conditions can produce mobilization, dilution and transformation with competing effects (van Vliet et al., 2023). Measurement time and frequency influence the observed distribution of water-quality data (Elfferich et al., 2024). Consequently, differences between site averages in an unequal monitoring design should not automatically be treated as independent spatial effects.

The present study examines three identified Sebou River monitoring locations: Fès, Kariat Ba Mohamed and M’Kannsa. The original 2024–2025 archive comprises a twelve-campaign temporal record at Fès and three campaigns collected on common calendar dates at the other two locations. The study connects geographical identification and source-level traceability with a comparison framework adapted to that sampling structure. Its objectives are to quantify site-specific chemistry and dispersion, test the persistence of observed contrasts under a seasonal-coverage restriction, compare the two sparsely sampled locations on their shared dates, and explore temporal associations at Fès. This combination identifies which contrasts are reproducible within the archive and which indicator rankings change between campaigns. Statistical river assessments and monitoring-design studies provide the methodological context (Chavarría Márquez et al., 2025; McDowell et al., 2024). The contribution is an auditable observational assessment for Sebou monitoring, rather than a new analytical technique or a causal source-apportionment model.

MATERIALS AND METHODS

Monitoring locations and sampling structure

The sampling locations are identified throughout as Fès, Kariat Ba Mohamed and M’Kannsa, corresponding to Sites 1, 2 and 3 in the source archive. The geographic names identify river-water monitoring locations in the Fès, Kariat Ba Mohamed and M’Kannsa areas. Samples represent untreated Sebou River water collected at intakes; the study does not evaluate the operation or performance of the associated facilities.

This correspondence is supported by the original worksheet headings, supplied location documentation and the archived project report (Anonymous, 2024). The cartographic reference coordinates are 34.0683° N, 4.9185° W for Fès; 34.3156° N, 5.1929° W for Kariat Ba Mohamed; and 34.3025° N, 5.4442° W for M’Kannsa (Table 1). They are approximate reference locations derived from supplied map views, not surveyed GPS positions of the sampling points; the Fès reference is provisional. Full decimal references and their provenance are recorded in `site_coordinates.csv` and the location documentation. Geographical names permit verification of site attribution. Author identities are withheld in the review copy. No measured river-distance sequence or sampling depth is assigned. The separate four-campaign 2024 project-report dataset is used as methodological documentation and is not pooled with the eighteen-campaign archive.

Eighteen site-campaign records were available (Table 1). All eighteen records were retained; iron, aluminium and ammonium were excluded from the principal quantitative analysis as explained below. Kariat Ba Mohamed and M’Kannsa were sampled on the same three dates, at different times within each day. None coincided with a Fès campaign. Fès covers winter, spring, summer and autumn, with two, four, two and four observations, respectively; Kariat Ba Mohamed and M’Kannsa cover spring twice and autumn once. Sample size is determined by the available monitoring record rather than a prospective power calculation (Lakens, 2022).

Documentary sampling and analytical methods

Sampling documentation includes the regional laboratory procedure 11PQ, version 01, November 2023 (ONEE, 2023), and NM ISO 5667-1:2012 (IMANOR, 2012), which reproduces ISO 5667-1:2006. The procedure specifies prevention of contamination, sample identification and cooled transport at 2–8 °C. These requirements describe the documented protocol; campaign-specific temperature logs and holding-time records were not supplied, so compliance for each sample is not asserted. The archived report describes collection in plastic bottles, field temperature and pH measurements, acidic permanganate oxidation and titration, and indophenol spectrophotometry for ammonium

Table 1. Sampling coverage and comparison structure of the original worksheets

Site and approximate map reference	n	Sampling dates	Comparison basis
Fès 34.0683, -4.9185 Provisional reference	12	31 Jan, 18 Mar, 23 May, 24 Jul, 25 Sep, 21 Nov 2024; 15 Jan, 26 Mar, 20 May, 23 Jul, 26 Sep, 27 Nov 2025	Temporal record; no exact date match with Kariat Ba Mohamed and M'Kannsa
Kariat Ba Mohamed 34.3156, -5.1929	3	29 Apr 2024; 21 Oct 2024; 30 Apr 2025	Same calendar dates as M'Kannsa
M'Kannsa 34.3025, -5.4442	3	29 Apr 2024; 21 Oct 2024; 30 Apr 2025	Same calendar dates as Kariat Ba Mohamed

Table 2. Documented analytical context and reporting constraints

Indicator group	Recorded output	Evidence and limitation
Temperature and pH	°C; pH units	Field measurements described in the archived report; campaign calibration logs unavailable
Field conductivity and turbidity	µS/cm at 20 °C; NTU	Worksheet field values; no mixture with laboratory conductivity
Permanganate oxidizability	mg O ₂ /L	Acidic heated oxidation and titration described in the report
Dissolved oxygen	mg O ₂ /L	Worksheet reporting; campaign-specific device and procedure require confirmation
Iron audit	mg/L in SpectrAA	Fe (Flamme); fractions, dilution history and final validation incompletely reconciled
Aluminium audit	µg/L in SpectrAA; mg/L in worksheets	Al (Four); conversion and dilution not fully reconciled for all campaigns
Ammonium audit	mg/L as recorded	Indophenol principle described in archived report; actual wavelength, basis and QC not established
Hardness and alkalinity	meq/L	EDTA and acid titration described in the report
Other retained ions and dry residue	mg/L	Source units preserved; complete campaign-specific procedures unavailable

(Anonymous, 2024). Its storage description is not used to override the later procedure. Table 2 separates documentary principles, evidence from instrument reports and unresolved validation information.

The principal analysis retains sixteen worksheet indicators. Field conductivity at 20 °C was used consistently and was not mixed with laboratory conductivity. Nitrate remains on the recorded mg/L basis without ion-to-nitrogen conversion. SpectrAA reports identify iron as Fe (Flamme), with concentration output in mg/L, and aluminium as Al (Four), with output in µg/L. The software screenshot identifies SpectrAA 5.4 PRO and an Agilent 240FS AA application; it is not a certificate of the hardware used for every historical campaign. The supplied flame guide lists recommended iron conditions, including 248.3 nm, but these recommendations do not establish the settings actually used (Atomic Absorption Analytical Methods, n.d.). No unverified wavelength, atomizer model, filtration, digestion or method accreditation is assigned to the campaigns.

The seventeen SpectrAA reports provide calibration curves and entries labelled BLANC,

MR, DUP and AJD, as well as sample identifiers and analytical units. Their print dates are distinguished from analysis and sampling dates. Three sample-level transcription amendments were confirmed by the authors on 13 October 2026: field dissolved Fe for 441/502 at Kariat Ba Mohamed and 447/502 at M'Kannsa, sampled on 30 April 2025, is 0.025 mg/L in each case instead of 0.25 mg/L; Al for 512/501 at Fès, sampled on 18 March 2024, is 0.18 mg/L instead of 1.80 mg/L. The Al export gives 180.55 µg/L (FES 2.pdf, p. 9), equivalent to 0.18055 mg/L and 0.18 mg/L after rounding. The corresponding total Fe outputs are 0.07 and 0.06 mg/L (501 502.pdf, p. 3). Original worksheet entries remain intact; the revised values, source cells and confirmation status are recorded separately in `correction_log.csv` and `revised_source_records.csv`. The confirmation applies to these entries and does not certify every historical fraction, dilution or quality-control result. S1 distinguishes instrumental readouts, confirmed amendments and validation information. Metals and ammonium remain in the documentary dataset; the sixteen-indicator principal analysis and six association tests do not depend on them.

Data preparation and descriptive analysis

Worksheet labels were matched explicitly because parameter row positions differ between sites. The three original XLSX files are supplied unchanged and their identities and byte-level checksums are recorded. `source_records.csv` preserves 738 extracted parameter entries with original units, dates, available time text, sample identifiers and source cells. `original_18_by_18_dataset.csv` preserves the 324 entries for eighteen indicators across eighteen campaigns; `dataset_schema.csv` documents labels, units and inclusion in the current analysis. A site-name correspondence accompanies the geographic relabelling. Sampling times are available for sixteen campaigns; no time was recorded for Fès on 18 March 2024 or 26 March 2025. Missing entries remain missing, zeros remain recorded values and less-than entries remain left-censored. Arithmetic means, medians, sample SD ($\text{ddof} = 1$), observed ranges and $\text{CV} = 100 \times \text{SD}/\text{mean}$ were calculated by site for the sixteen principal indicators. CV was omitted for pH and Celsius temperature. `reproduce_analysis.py` specifies the calculations and regenerates Figures 1–3 (Helsel et al., 2020). A separate amendment script preserves the three confirmed corrections in derived files without changing original evidence or the principal results.

The M’Kannsa aluminium entry $<0.03 \text{ mg/L}$ is retained literally in the source record. No aluminium mean or quantitative metal comparison is used in the current main analysis. A separate historical audit documents the earlier bounded mean ($0.43/3, 0.46/3$) mg/L , assuming a nonnegative censored entry, solely to permit verification of the submitted calculation. The ten earlier correlations and all earlier manuscript tables are also preserved separately; the new historical audit algorithm is distinguished from the unavailable historical implementation. Recomputed Monte Carlo p values can differ slightly and are not represented as identical earlier output. Other censored trace-element records are described by numeric, censored and missing counts without substituted means or risk scores. Reporting boundaries are not independently verified LOD/LOQ, and no pooled eighteen-observation mean represents the river.

Comparison framework and exploratory statistics

Site-specific summaries describe the actual sampling windows. Same-date Kariat Ba

Mohamed–M’Kannsa differences were calculated for each of the three shared campaigns. These are paired calendar-day observations, not simultaneous samples; no travel-time correction was possible. The Fès record was also restricted to its eight spring and autumn campaigns to check whether the principal observed contrasts depended solely on inclusion of winter and summer. This restriction does not align exact dates or remove hydrological confounding. No three-site analysis of variance or site-effect significance test was performed.

Exploratory Spearman associations were recalculated within the twelve-campaign Fès record using conductivity, turbidity, permanganate oxidizability and nitrate. All six pairs among these four retained indicators are reported, using average ranks for ties. For each pair, 99,999 random permutations of one centred rank vector were generated, in the pair order reported in Table 5, using seed 20261012. Two-sided Monte Carlo p values use the plus-one correction and 100,000 as the denominator. Holm adjustment covers all six tests. Coefficients were recalculated after omitting each campaign in turn; these sensitivity ranges are not confidence intervals. The script and CSV outputs accompany the revision.

Permutation reference tests assume exchangeable campaigns and do not model temporal dependence. No correlation tests were performed within the three-observation sites. Principal component analysis can reduce dimensionality (Jolliffe and Cadima, 2016), but a pooled analysis would combine temporal and site structure and was not used for source attribution. Iron, aluminium and ammonium do not enter the revised exploratory family, and no ammonium sensitivity statistic is used to support a principal conclusion.

RESULTS

Site-specific ionic and general chemical conditions

Table 3 summarises the sixteen retained indicators; Figure 1 shows selected values at their actual dates. Water was slightly alkaline at the recorded sampling times, with site mean pH values of 8.15, 8.02 and 8.09. Conductivity ranged from 962 to 1130 $\mu\text{S/cm}$ at Fès, 1440 to 1820 $\mu\text{S/cm}$ at Kariat Ba Mohamed, and 1340 to 2010 $\mu\text{S/cm}$ at M’Kannsa. Corresponding means were 1062, 1580 and 1577 $\mu\text{S/cm}$. Thus, similar Kariat Ba

Table 3. Site-specific means and observed ranges for the sixteen principal indicators. Fès n = 12; Kariat Ba Mohamed and M’Kannsa n = 3 each. Nitrate retains its worksheet reporting basis. Metal amendments and analytical traceability are documented in S1

Indicator and unit	Fès	Kariat Ba Mohamed	M’Kannsa
Temperature (°C)	20.3 (13.2–27.6)	20.7 (18.5–23.0)	21.4 (19.0–25.6)
pH (pH units)	8.15 (7.99–8.38)	8.02 (7.98–8.11)	8.09 (7.94–8.23)
Conductivity ($\mu\text{S}/\text{cm}$ at 20 °C)	1062 (962–1130)	1580 (1440–1820)	1577 (1340–2010)
Turbidity (NTU)	87 (51–140)	69 (19–130)	109 (37–170)
Dry residue (mg/L)	774.5 (650.0–1000.0)	1123.3 (950.0–1300.0)	1163.3 (980.0–1500.0)
Sodium (mg/L)	117.9 (103.0–125.0)	195.3 (114.0–269.0)	244.0 (159.0–359.0)
Potassium (mg/L)	2.4 (1.2–3.6)	15.5 (7.5–20.0)	16.3 (9.8–20.0)
Calcium (mg/L)	56.9 (54.5–60.9)	99.5 (92.2–114.0)	98.7 (64.1–124.0)
Fluoride (mg/L)	0.14 (0.10–0.17)	0.25 (0.23–0.26)	0.32 (0.32–0.33)
Hardness (meq/L)	6.1 (5.8–6.9)	6.5 (5.8–7.2)	5.7 (3.7–7.6)
Alkalinity (meq/L)	5.3 (5.1–5.5)	5.2 (5.0–5.6)	4.1 (2.3–5.7)
Oxidizability (mg O_2/L)	2.2 (0.9–3.3)	5.9 (4.1–7.5)	6.5 (5.0–8.0)
Dissolved oxygen (mg O_2/L)	7.2 (7.0–7.9)	6.9 (6.5–7.4)	7.2 (6.6–8.0)
Nitrate (mg/L)	14.5 (12.1–17.8)	18.0 (10.9–29.3)	14.4 (10.5–21.2)
Chloride (mg/L)	203.4 (185.0–215.0)	346.7 (259.0–465.0)	409.0 (263.0–612.0)
Sulfate (mg/L)	24.6 (20.1–28.9)	82.8 (68.7–90.8)	74.6 (49.2–103.0)

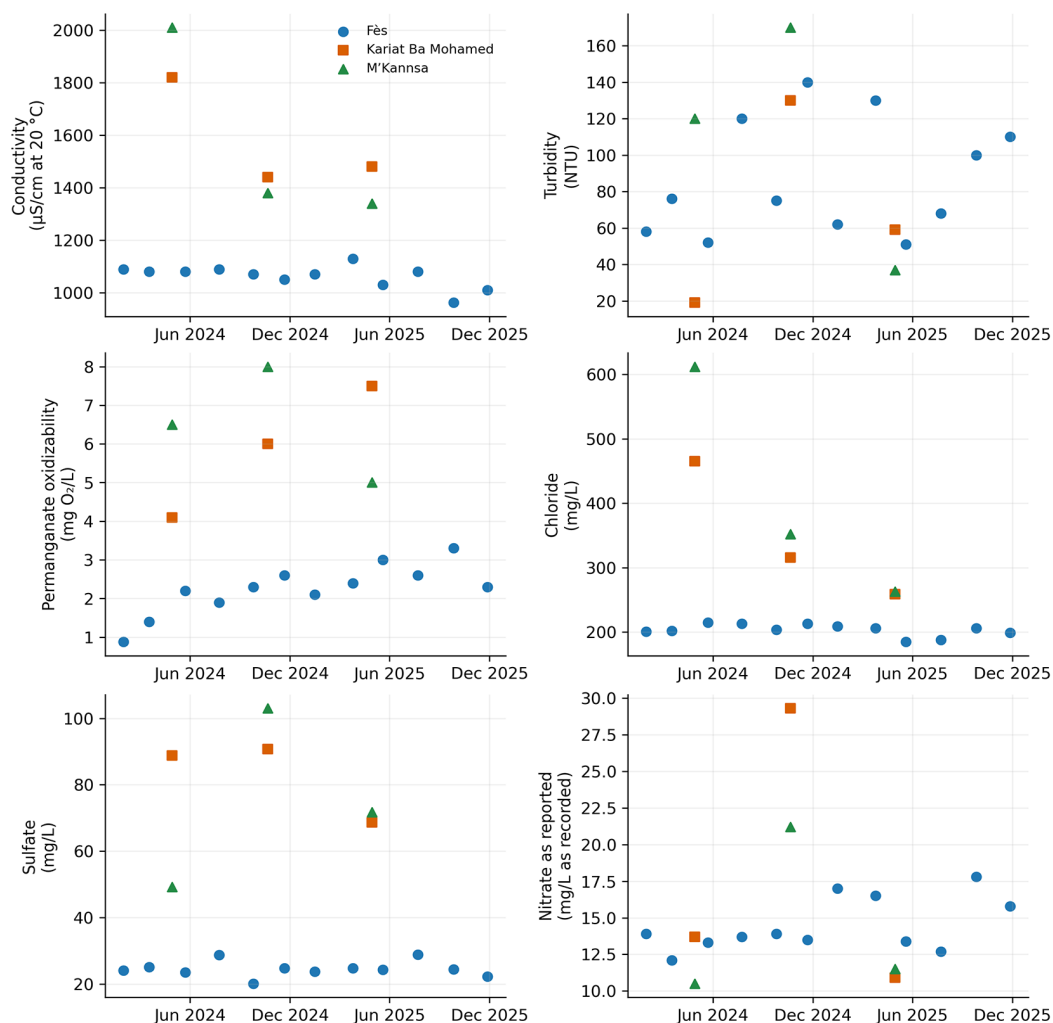


Figure 1. Selected indicators at the actual sampling dates for all three sites. Each symbol is one campaign; observations are not temporally interpolated or treated as exact date matches between Fès and the other sites

Mohamed and M'Kannsa means concealed different campaign-level rankings. Dry-residue means were 774.5, 1123.3 and 1163.3 mg/L. Throughout the Results, higher means higher values among the supplied campaign records; it does not establish a persistent geographical gradient.

Chloride averaged 203.4, 346.7 and 409.0 mg/L at Fès, Kariat Ba Mohamed and M'Kannsa, respectively. The observed Fès range, 185–215 mg/L, did not overlap either Kariat Ba Mohamed (259–465 mg/L) or M'Kannsa (263–612 mg/L). Sulfate also showed non-overlapping recorded ranges: 20.1–28.9, 68.7–90.8 and 49.2–103.0 mg/L. Potassium, calcium and fluoride were consistently higher in the recorded campaigns at Kariat Ba Mohamed and M'Kannsa than at Fès. These are observed distributions over different sampling dates.

Oxidizable matter and nitrate

Permanganate oxidizability averaged 2.25 mg O₂/L at Fès, compared with 5.87 and 6.50 mg O₂/L at Kariat Ba Mohamed and M'Kannsa. The observed ranges were 0.88–3.30, 4.10–7.50 and 5.00–8.00 mg O₂/L, respectively. Dissolved oxygen ranged from 7.0 to 7.9, 6.5 to 7.4 and 6.6 to 8.0 mg O₂/L. Higher oxidizability in the sparse-site

campaigns did not coincide with uniformly lower dissolved oxygen in all observations. Kariat Ba Mohamed nitrate reached 29.3 mg/L in October 2024; site means were 14.47, 17.97 and 14.40 mg/L. These quantities retain their worksheet reporting basis without nitrogen conversion. Figure 2 displays individual observations of turbidity, oxidizability, nitrate and dissolved oxygen.

The confirmed field dissolved Fe entries are 0.025 mg/L at Kariat Ba Mohamed and M'Kannsa on 30 April 2025; their corresponding total Fe values are 0.07 and 0.06 mg/L. The confirmed Al entry at Fès on 18 March 2024 is 0.18 mg/L. These sample-specific values are documented in S1 with source identifiers and instrument-page references. They are not extrapolated to other campaigns and do not drive the principal figures or association tests.

Same-date comparisons of Kariat Ba Mohamed and M'Kannsa

Table 4 and Figure 3 compare the three shared dates. M'Kannsa chloride was higher than Kariat Ba Mohamed on every date, by 147, 36 and 4 mg/L. Conductivity showed M'Kannsa minus Kariat Ba Mohamed differences of +190, –60 and –140 µS/

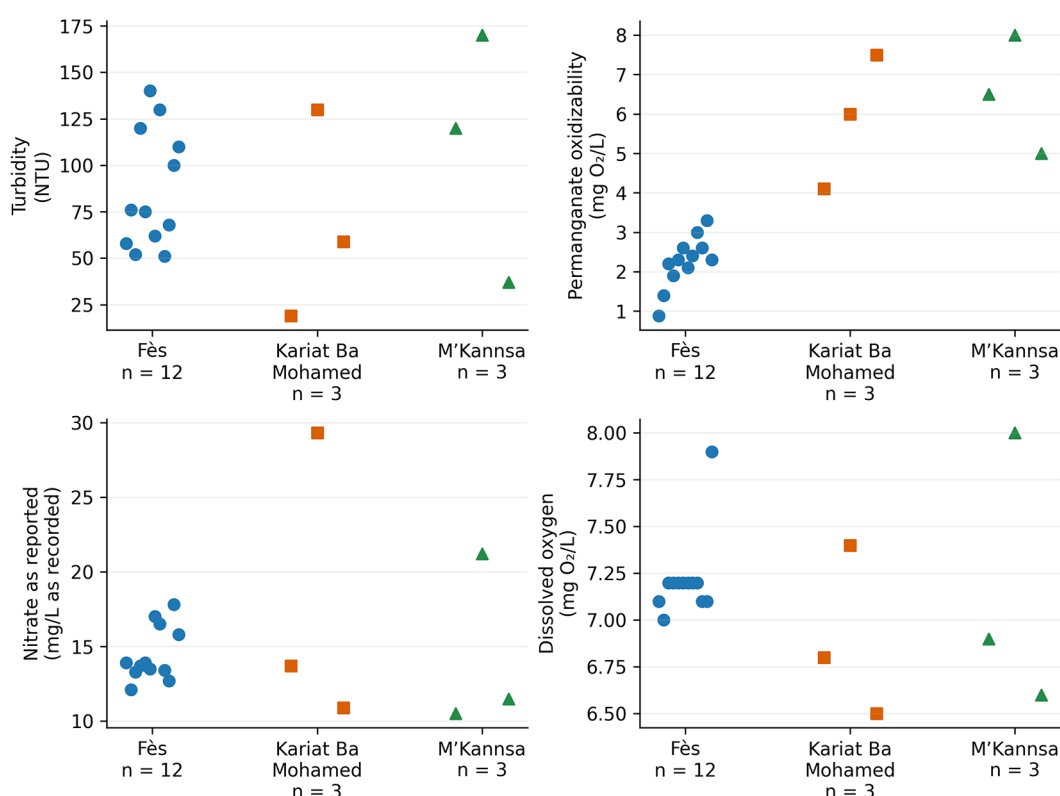
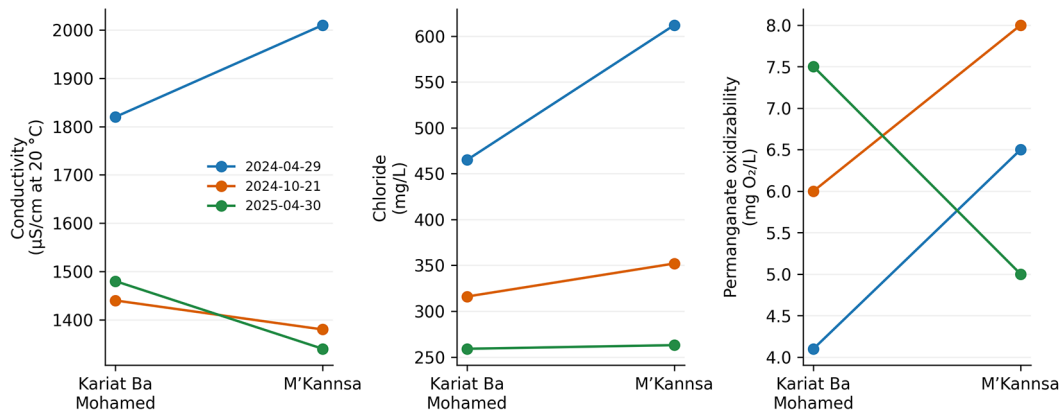


Figure 2. Individual observations of four retained indicators by site. Horizontal offsets separate symbols and do not represent time or river distance. Each symbol represents one campaign; site sample counts differ

Table 4. Same-date Kariat Ba Mohamed / M’Kannsa observations. Values are in the order Kariat Ba Mohamed / M’Kannsa; no Fès measurements were collected on these dates

Indicator and unit	29 Apr 2024	21 Oct 2024	30 Apr 2025
Conductivity ($\mu\text{S}/\text{cm}$ at 20 °C)	1820 / 2010	1440 / 1380	1480 / 1340
Chloride (mg/L)	465.0 / 612.0	316.0 / 352.0	259.0 / 263.0
Sulfate (mg/L)	88.8 / 49.2	90.8 / 103.0	68.7 / 71.7
Turbidity (NTU)	19 / 120	130 / 170	59 / 37
Oxidizability ($\text{mg O}_2/\text{L}$)	4.1 / 6.5	6.0 / 8.0	7.5 / 5.0

**Figure 3.** Same-date contrasts between Kariat Ba Mohamed and M’Kannsa for conductivity, chloride and permanganate oxidizability. Each line joins observations from one calendar-day campaign and does not represent a river-distance profile

cm; the ordering therefore changed. Oxidizability was higher at M’Kannsa in both 2024 campaigns but lower in April 2025. Turbidity was higher at M’Kannsa in April and October 2024 but lower in April 2025. No stable overall ranking of the two locations followed from these three campaigns.

Fès variability and sensitivity to sampling coverage

Within Fès, conductivity and chloride had CV values of 4.1% and 4.6%, compared with 36.5% for turbidity and 29.0% for permanganate oxidizability. These values describe relative dispersion within twelve recorded campaigns and do not rank environmental toxicity or ecological risk. Turbidity means were 60.0 NTU in the two winter observations and 106.3 NTU in the four autumn observations. These seasonal summaries do not establish recurrent seasonal effects.

Restricting Fès to its eight spring and autumn campaigns gave observed ranges of 962–1130 $\mu\text{S}/\text{cm}$ for conductivity, 185–215 mg/L for chloride, 20.1–25.1 mg/L for sulfate and 1.40–3.30 $\text{mg O}_2/\text{L}$ for oxidizability. All recorded values of these four indicators at Kariat Ba Mohamed

and M’Kannsa remained above the Fès subset maxima. The contrasts therefore do not depend solely on inclusion of Fès winter and summer campaigns. Exact dates, flow conditions and analytical comparability remain uncontrolled.

The six-pair Fès correlation family is reported in Table 5. Conductivity and oxidizability had the largest absolute coefficient ($\rho = -0.590$; permutation $p = 0.0470$; Holm-adjusted $p = 0.2819$). No association met the adjusted 0.05 criterion. Leave-one-campaign-out coefficients for conductivity-oxidizability ranged from -0.780 to -0.465. These are influence ranges, not evidence of a confirmed process.

Censored trace-element reporting

Lead, arsenic, selenium, chromium, cadmium and nickel were frequently reported below a worksheet boundary (Table 6). Numeric entries coexist with censored entries; neither pattern demonstrates absence, validated detection or regulatory compliance. Table 6 summarises worksheet reporting completeness, without concentration averages or substituted values. It is not a batch-validation assessment.

Table 5. Recalculated exploratory associations within Fès only. $n = 12$ for each pair; 99,999 permutations; seed 20261012; Holm correction across all six tests

Indicator pair	rho	Permutation p	Holm p
Conductivity / Turbidity	0.039	0.9068	1.0000
Conductivity / Oxidizability	-0.590	0.0470	0.2819
Conductivity / Nitrate	-0.237	0.4541	1.0000
Turbidity / Oxidizability	0.140	0.6584	1.0000
Turbidity / Nitrate	0.270	0.3943	1.0000
Oxidizability / Nitrate	0.149	0.6406	1.0000

Table 6. Number of numeric / censored / missing records for selected trace elements. Reporting boundaries are retained in the source record

Element	Fès	Kariat Ba Mohamed	M'Kannsa
Lead	3 / 9 / 0	0 / 3 / 0	0 / 3 / 0
Arsenic	1 / 11 / 0	1 / 2 / 0	1 / 2 / 0
Selenium	1 / 11 / 0	0 / 3 / 0	1 / 2 / 0
Chromium	7 / 5 / 0	1 / 2 / 0	1 / 2 / 0
Cadmium	1 / 11 / 0	0 / 3 / 0	0 / 3 / 0
Nickel	4 / 8 / 0	1 / 2 / 0	1 / 2 / 0

DISCUSSION

Meaning of the observed chemical contrasts

The strongest descriptive contrasts concern the ionic indicators and permanganate oxidizability. Non-overlapping observed conductivity, chloride, sulfate and oxidizability ranges distinguish the supplied Fès record from the three campaigns at each other site. The spring–autumn restriction shows that including different calendar seasons is not the sole explanation for these recorded contrasts. However, the comparison still combines site, date and potentially analytical effects. It establishes differences in the supplied records, not a site effect isolated from hydrology or sampling practice.

Major-ion patterns can reflect several interacting natural and human influences (Wu et al., 2021), while urban and rural water-quality drivers vary with catchment conditions (Anh et al., 2023). Higher chloride, sulfate and conductivity should therefore be interpreted jointly as evidence of different recorded ionic conditions. They do not identify saline inputs, wastewater fractions or particular land uses. Concurrent discharge and source information would be necessary to evaluate enrichment, dilution and transport.

The Kariat Ba Mohamed–M'Kannsa comparisons provide a more direct temporal alignment than comparisons with Fès. Higher M'Kannsa chloride was observed on all three shared dates, but the difference declined from 147 to 4 mg/L. Conductivity and oxidizability rankings changed. These indicator-specific observations describe the sampled river water and do not establish an overall environmental ranking of the locations. The record does not identify a discharge source or attribute responsibility to a facility, its operator or an institution.

Oxidizability, turbidity and oxygen conditions

Higher oxidizability at Kariat Ba Mohamed and M'Kannsa suggests a greater operationally measured oxidizable-matter signal in those samples. Permanganate oxidizability is not a direct measurement of all organic carbon and should not be equated with biochemical or chemical oxygen demand. The maintained dissolved-oxygen snapshots do not establish the absence of oxygen depletion between sampling times. Hydrological and biological responses may have different temporal scales, and climate-related mobilization and dilution can act in opposite directions (van Vliet et al., 2023).

Turbidity is an optical property, not suspended-solids mass concentration. Its ranges overlap across sites, unlike the selected ionic indicators and oxidizability. Within Fès, turbidity and oxidizability also had a weak rank association despite higher autumn averages for both. These observations support treating the indicators as distinct monitoring signals rather than interchangeable measures of one pollutant burden.

Regional context and metal interpretation

The regional literature documents marked chemical and contaminant changes across river locations (Perrin et al., 2014) and distinguishes dissolved and particulate element behavior (Hayzoun et al., 2015). The present record adds site-specific observations from 2024–2025, with a longer temporal sequence at Fès and calendar-day comparisons between Kariat Ba Mohamed and M'Kannsa. It does not demonstrate improvement or deterioration relative to earlier studies, because equivalent sampling points, hydrology, fractions and methods were not established.

Sediment experiments and surveys motivate examination of water and sediment together (Hassimi et al., 2019; Dra et al., 2019), but sediment concentrations cannot be compared directly with water concentrations. The confirmed amendments restore the stated values for three documented entries, including the distinction between dissolved and total Fe and the $\mu\text{g/L}$ -to- mg/L conversion for Al. These corrections improve the transparency of the metal record. S1 retains campaign-specific instrumental concordances and distinguishes them from a complete validation of all archived metal results. The ionic, turbidity and oxidizability findings are independently supported by the sixteen-indicator principal analysis.

Statistical interpretation and monitoring implications

Within-site exploratory analysis avoids pooling a dense Fès time series with two sparse sites. None of the Fès associations remained significant after Holm correction, but this does not prove the absence of environmental relationships. Statistical significance does not measure environmental importance, and large p values are not proof of the null hypothesis

(Wasserstein and Lazar, 2016). Conversely, a nominal unadjusted p value should not be treated as confirmation of a mechanism. Reporting the full family and influence ranges makes this distinction transparent.

High-frequency monitoring can reveal variations missed by intermittent campaigns (Rode et al., 2016), and the interpretation of observed concentrations depends on measurement frequency and timing (Elfferich et al., 2024). For these locations, the supplied records justify considering complementary ionic, turbidity and oxidizability indicators, with periodic nutrients and metals. A coordinated programme that samples all three locations on shared dates, records flow and rainfall, and verifies laboratory procedures would better distinguish temporal variation from location-related contrasts. The present study has not tested the performance of such a programme.

Scope and limitations

The archive contains eighteen campaign records, with twelve at Fès and three each at Kariat Ba Mohamed and M'Kannsa. Unequal seasonal coverage and the absence of shared dates with Fès mean that location and temporal conditions cannot be separated as independent effects. Shared-date observations at the other two locations differ in within-day timing; flow, travel time and rainfall are not available for adjustment. The seasonal restriction at Fès tests sensitivity to calendar coverage and does not create a matched hydrological design. The reported contrasts therefore apply to the monitored campaigns.

Rank associations are exploratory because temporal exchangeability was not established; a non-significant adjusted result does not establish absence of a relationship. Primary worksheets, instrument exports and methodological documents permit source tracing, while S1 identifies which campaign-specific custody, dilution, detection-limit and batch-acceptance details are actually documented. The three confirmed amendments are distinct from complete validation of all historical measurements. Approximate map references identify the locations without certifying GPS sampling positions. The study consequently reports observed hydrochemical patterns and indicator variability without regulatory classification, ecological-risk estimates, mass fluxes or causal source attribution.

CONCLUSIONS

The supplied monitoring records showed higher conductivity, chloride, sulfate and permanganate oxidizability at Kariat Ba Mohamed and M'Kannsa than at Fès, with non-overlapping observed ranges. These contrasts persisted when Fès was restricted to spring and autumn. Across the three shared Kariat Ba Mohamed–M'Kannsa dates, chloride was consistently higher at M'Kannsa, whereas conductivity and oxidizability rankings changed. Within Fès, conductivity and chloride had lower relative dispersion than turbidity, and none of six exploratory rank associations remained significant after Holm correction. These conclusions rely on the retained indicators and do not require iron, aluminium or ammonium. They describe the monitored campaigns rather than an independent site effect or a general condition for the Sebou basin.

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