Characterizing Temporal Variability in Continuous Water Quality Data Using Frequency Analysis: Implications for Sampling Strategy Design

BME FACULTY OF CIVIL ENGINEERING

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RIVER BASINS

INTRODUCTION

Objective

Continuous water quality monitoring generates high-frequency datasets from which sampling frequency recommendations are typically derived via spectral analysis — implicitly treating the dominant period as a fixed property of each parameter. This study tests that assumption.

Is there a single optimal sampling frequency for a given parameter — or does it depend on the observation window and prevailing hydrological and seasonal regime?

Findings in brief

Five-month continuous monitoring data (37,171 observations, 5-min interval) from Koppány-patak at Törökkoppány, Hungary, were analysed by Wiener–Khinchin PSD at full-series, monthly, and weekly scales. The dominant spectral period changes with observation window for every parameter, and no parameter yields a stable Nyquist recommendation across this five-month record.

DATASET

observations	sampling interval	reviewed period
n=37,171	**5 min**	**5 months**

Site: Koppány-patak, Törökkoppány
Period: 25 Jul – 30 Nov 2025
Parameters: waterTemp · O_2 mg/l & % · turbidity · conductivity · water level

METHOD

Wiener–Khinchin PSD (Somlyódy & Jolánkai, 1986)

① Normalised autocorrelation R(k) via xcorr
② PSD via FFT of R(k)
③ f_dom = argmax S̃(f), DC excluded
④ Min Δt = T_dom / 2 (Nyquist criterion)

Three nested temporal scales

Full series · Jul–Nov 2025
Monthly · 5 calendar months
Weekly · ISO weeks W30–W48

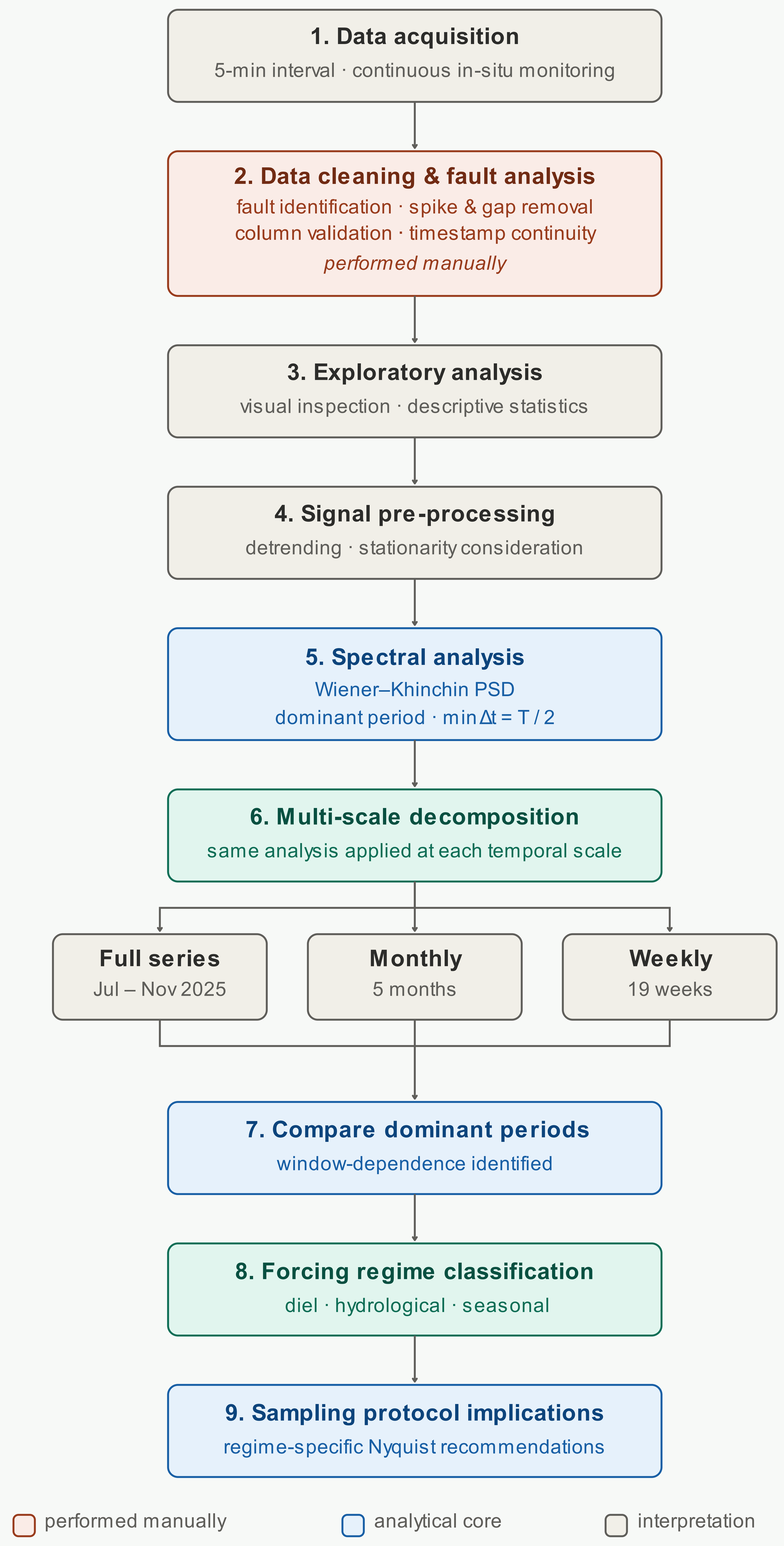

Figure 1. Methodological workflow of this study

Beyond sampling design, the Wiener–Khinchin PSD method is suited to answering predefined, a priori questions about expected periodicities. If a process is known to operate at a specific timescale (e.g. the 24-hour photosynthesis–respiration cycle), spectral analysis of field data can confirm whether that periodicity is detectable under real conditions and under which regimes it dominates. The method thus serves a confirmatory role alongside its conventional exploratory one.

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Selected references

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RESULTS

1 Full-series analysis: O_2 and LDO saturation recover 24 h — all other parameters: multi-day to seasonal

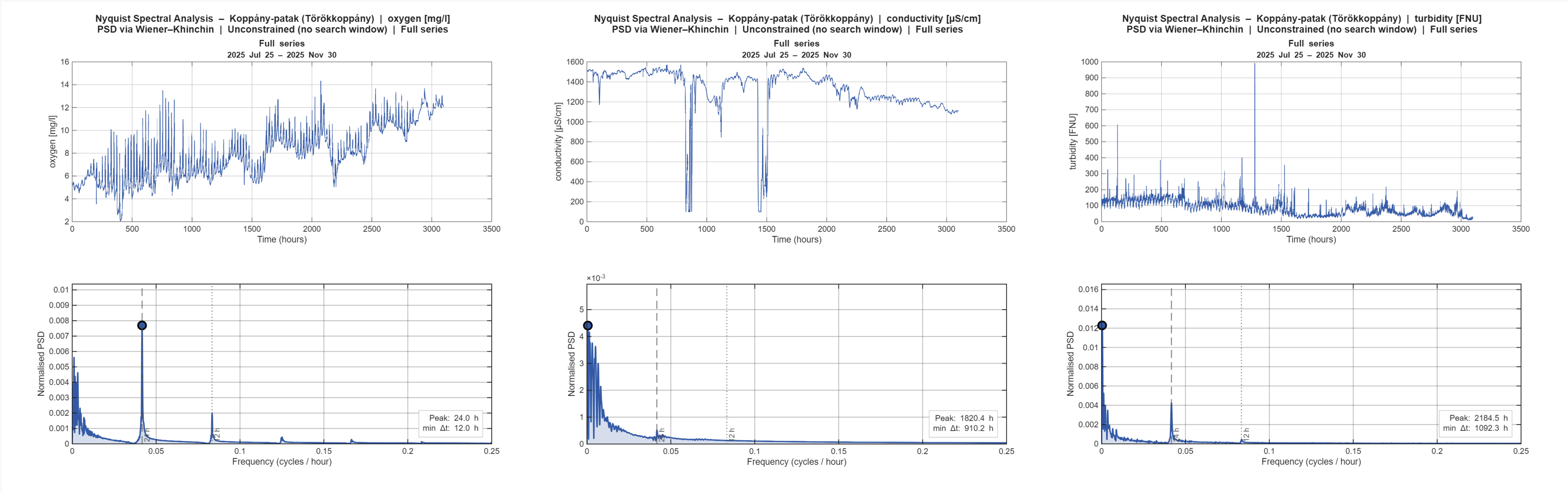

Figure 2. Dominant spectral period at full-series scale. O_2: 24.0 h. Conductivity: 1820 h. Turbidity: 2185 h. Full-series analysis aggregates across regimes — only the highest-variance regime appears.

2 Monthly analysis: O_2 diel period dominant only in August — seasonal trend masks diel signal from September onward

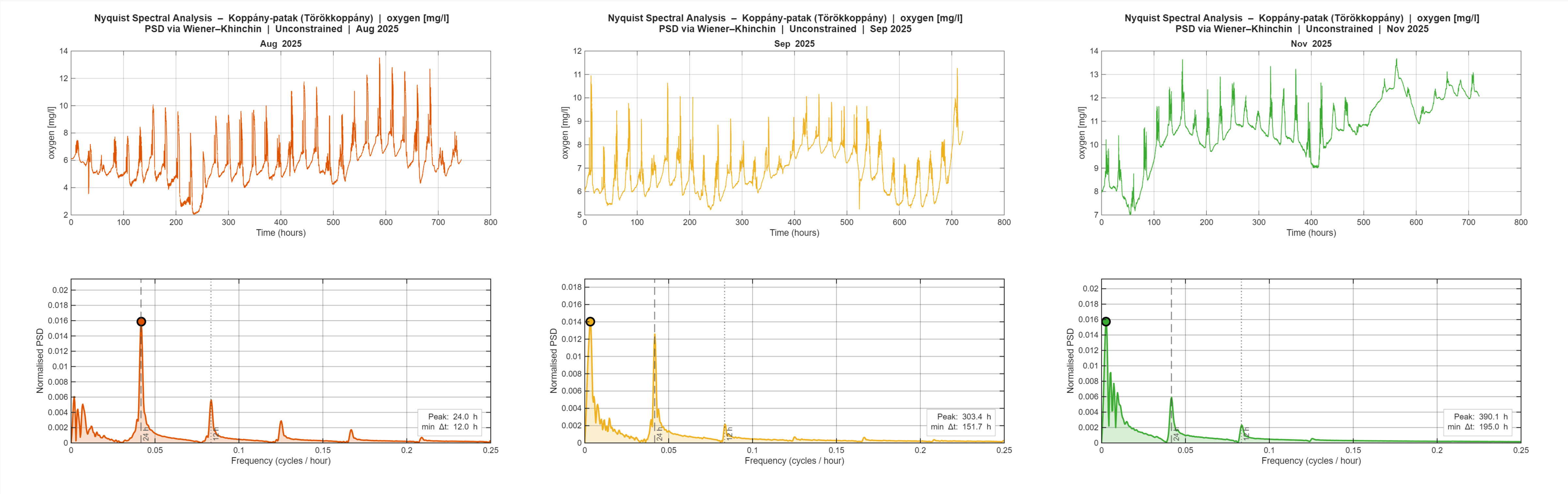

Figure 3. O_2 dominant period: 24 h (Aug) → 303–390 h (Sep–Nov). No parameter yields a consistent dominant period across all five months.

3 Weekly baseflow (W35: 25–31 August): clean diel signal — O_2 and waterTemp ~24 h, turbidity shows diel structure

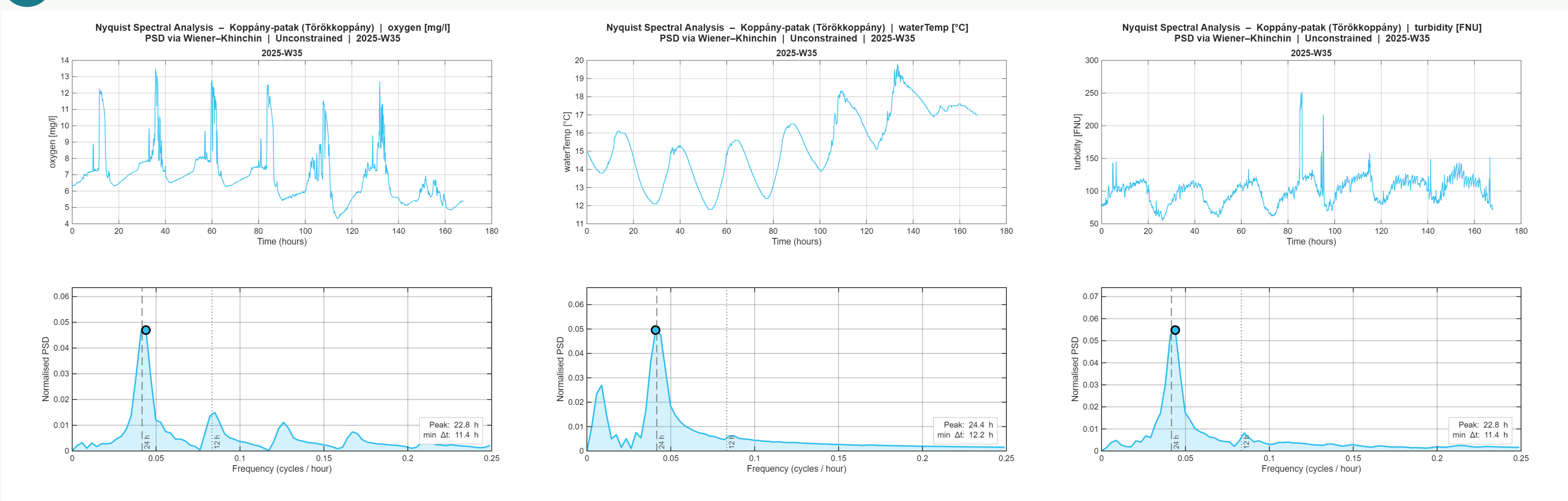

Figure 4. Under summer baseflow: O_2 and waterTemp exhibit ~24 h dominant periods. Min Δt = 12 h. Turbidity exhibits a diel spectral signal (~24 h) during calm summer baseflow conditions, which is lost when hydrological events occur.

4 Weekly flood event (W43: 20–26 October): diel signal lost — spectral coherence between O_2 and turbidity is diagnostic

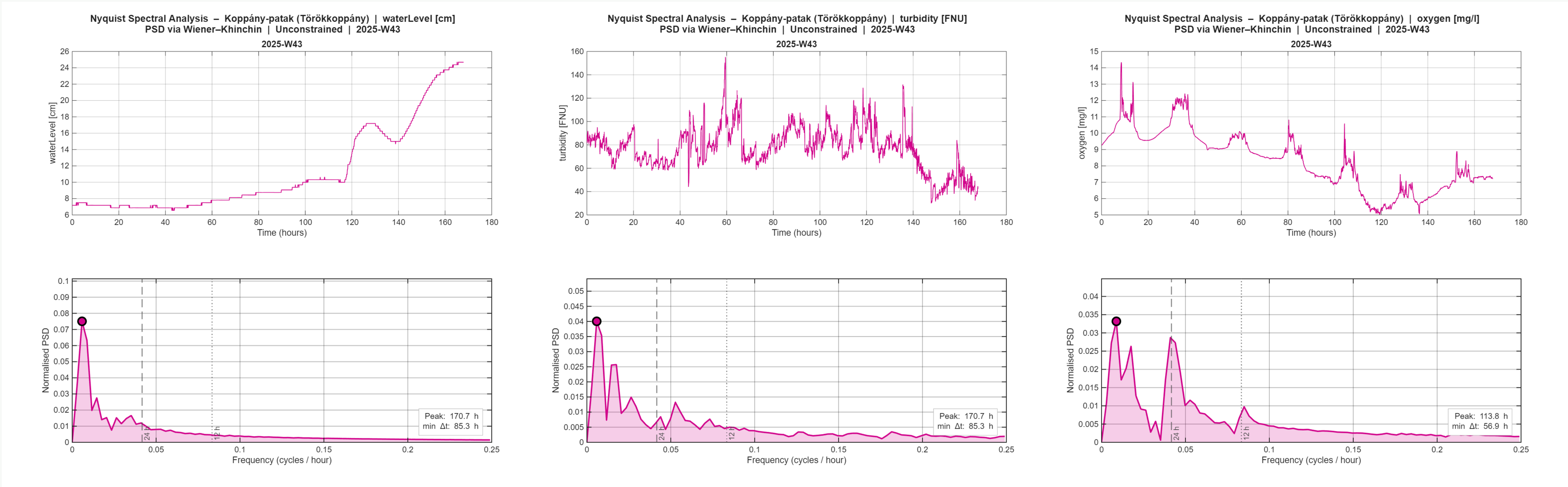

Figure 5. W43: turbidity spike during the water level rise, O_2 falls to 5 mg/l. Cross-parameter simultaneous loss of diel signal confirms hydrological forcing rather than light limitation.

5 Forcing regime classification

Parameter	Dominant period (h)	Dominant period (d)	Min Δt (h)
O_2 [mg/l]	24.0	1.000	12.0
LDO saturation [%]	24.0	1.000	12.0
Water temperature [°C]	1365.3	56.888	682.7
Turbidity [FNU]	2184.5	91.021	1092.3
Conductivity [μS/cm]	1820.4	75.850	910.2
Water level [cm]	2730.7	113.779	1365.3

Table 1. Dominant spectral period and implied minimum sampling interval at full-series scale (25 Jul – 30 Nov 2025).

Forcing regime	Sensitive parameters	Dominant timescale	Nyquist implication
Diel biological	O_2 [mg/l], LDO sat. [%], turbidity [FNU]*	~24 h	Min Δt = 12 h (summer baseflow only)
Hydrological event	Water level, turbidity [FNU]*, conductivity	2–5 d	Resolve hydrograph limb; diel interval irrelevant
Seasonal trend	Water temperature, conductivity	Weeks–months	Low-frequency sampling sufficient; diel interval wastes resources

**Turbidity participates in both Regime 1 and Regime 2 depending on hydrological conditions — diel signal dominant during calm baseflow weeks, replaced by event-scale forcing during flood pulses*

Table 2. Forcing regime classification of the five study parameters.

PRACTICAL IMPLICATION

The optimal sampling interval is a property of the forcing regime, not of the parameter. A single fixed frequency will simultaneously oversample in some conditions and undersample in others. Effective monitoring requires adaptive, regime-aware protocols.

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