Supplementary Material S1

Converting natural to aerated lagoons at the Mrirt wastewater treatment plant (Morocco): monthly monitoring data, statistical analyses and energy indicators

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This document accompanies the manuscript JEENG-10307-2026-01 (Journal of Ecological Engineering). It describes the data sources and calculation procedures, and reports all statistical tests. Supplementary Data S2 (Excel workbook) contains the complete monthly dataset, and Supplementary Code S3 (Python script) reproduces every table and figure below.

S1. Data sources and methods

S1.1 Origin of the data

All data were provided by ONEE – Water Branch (Office National de l'Électricité et de l'Eau Potable) from the operating records and routine laboratory monitoring of the Mrirt WWTP. Two complete calendar years are compared: January–December 2015 (natural lagooning, reference year) and January–December 2024 (two-stage aerated lagooning, after conversion). The analyses were performed by the same ONEE laboratory with the same analytical methods in both years. The 2015 water-quality data are those analysed by Allaoui et al. (2019).

Sampling followed the routine monitoring procedure of ONEE – Water Branch. Influent was sampled at the plant inlet downstream of pretreatment, and treated effluent at the outlet of the final settling basin. Grab samples were collected weekly, so that each monthly value is the arithmetic mean of four to five determinations. As these are means of discrete samples rather than flow-weighted composites, they are interpreted as indicative monthly values; the variability within each month is represented by the four to five independent weekly samples. Samples were handled and analysed at the ONEE – Water Branch regional laboratory, which holds NM ISO/IEC 17025:2018 accreditation for physico-chemical and microbiological water analyses, following the French standards in force for water analysis and the associated reference procedures (AFNOR, 2020; Rodier et al., 2016). The method principle for each parameter is given in Table S0; all reported concentrations were well above the quantification limits of these methods.

Table S0. Parameters, analytical methods and data availability.

Parameter	Unit	Method principle (AFNOR, 2020; Rodier et al., 2016)	2015	2024
BOD5	mg/L	Five-day incubation at 20 °C	Influent, effluent	Influent, effluent
COD	mg/L	Dichromate oxidation	Influent, effluent	Influent, effluent
TSS	mg/L	Filtration on glass-fibre filter, drying at 105 °C	Influent, effluent	Influent, effluent
pH	–	Electrometric (pH probe)	Not measured	Influent, effluent
Electrical conductivity	µS/cm (25 °C)	Electrometric (conductivity cell), referenced to 25 °C	Not measured	Influent, effluent
Dissolved oxygen	mg/L	Electrometric (oxygen probe)	Not measured	Influent, effluent
Flow	m³/d	Pump hours × rated capacity (2015); flowmeters (2024)	Influent (estimated)	Influent, effluent
Electricity	kWh/month	Invoices of the national electricity operator (plant-level metering)	Total	Total; lift-station allocation

Analyses performed at the ONEE – Water Branch regional laboratory (NM ISO/IEC 17025:2018 accreditation). All reported concentrations were well above the quantification limits of the methods.

S1.2 Flow data

In 2015 the influent flowmeter had been out of service since March 2013. Daily inflow was therefore estimated from the operating hours of the lift pumps multiplied by their rated capacity (Supplementary Data S2, sheet Daily_flow_2015; Fig. S5). Thirteen days show zero pumped flow (20–25 January, 23

February, 23 March and 1–5 August). Monthly means include these days, because they correspond to the volume actually pumped and to the electricity used. Excluding them would raise the annual mean inflow from 3,164 to 3,286 m³/d (+3.8%).

In 2024 both influent and effluent flows were measured. The effluent flow was on average 22.4% lower than the influent flow, which may reflect evaporation, infiltration through the pond bottoms or metering differences. Removal efficiencies in the manuscript are concentration-based (Eq. 1). Load-based efficiencies, which account for this volume loss, are given in Table S4 for information only.

S1.3 Electricity data

Monthly electricity consumption was taken from the invoices of the national electricity operator, which cover the whole installation. Metering is at plant level only, without process-level sub-metering, so consumption cannot be attributed to individual items of equipment. For 2024, the records distinguish a fixed allocation of 7,000 kWh/month for the inlet lift station. In 2015 total consumption ranged from 6,135 to 7,655 kWh/month, which is of the same order. This is consistent with a natural-lagoon configuration in which lift pumping is the only significant electrical load. In 2024, oxygen is supplied by a fine-bubble diffused-air system (blowers feeding diffusers on the basin floor) rather than by surface aerators.

S1.4 Calculations

Removal efficiency: η (%) = (Cin − Cout)/Cin × 100, computed for each month; annual values are means of the monthly efficiencies. Daily load removed (kg/d) = Qin × (Cin − Cout)/1000. Daily electricity (kWh/d) = monthly consumption / number of days in the month, using the actual calendar (February 2024 = 29 days). Specific energy: kWh/m³ = daily electricity / Qin; kWh/kg removed = daily electricity / daily load removed. Energy ratios are reported both as the mean of the twelve monthly ratios and as the ratio of annual totals, because the two differ mathematically.

S1.5 Statistical analysis

Monthly values (n = 12 per year) were summarised as mean ± standard deviation, 95% confidence interval of the mean (t distribution), median and range. Normality was checked with the Shapiro–Wilk test. Between-year differences were tested with Welch's t-test (unequal variances) and, as a non-parametric check, the Mann–Whitney U test. Effect sizes are given as Hedges' g, and p-values were adjusted with the Holm procedure across the twelve comparisons (Holm, 1979).

Pearson correlations were computed only between measured variables that share no term by construction. Removal efficiencies and energy ratios were excluded from the matrices to avoid spurious correlations of ratios (Pearson, 1897). This gives 14 variables (91 pairs) for 2024 and 8 variables (28 pairs) for 2015. For each pair we report r with its 95% confidence interval (Fisher z-transformation), the unadjusted p-value, the false-discovery-rate q-value (Benjamini & Hochberg, 1995), the Bonferroni-adjusted p-value, Spearman's ρ as a robustness check, and the largest Cook's distance of the corresponding simple linear regression to flag influential months. The effect of scale on energy use was tested by ordinary least-squares regression of absolute daily electricity on influent flow, influent BOD5 load and BOD5 load removed.

All analyses were run with Python 3.12.3 (NumPy 2.4.4, pandas 3.0.2, SciPy 1.17.1, statsmodels 0.15.0, matplotlib 3.10.8) using Supplementary Code S3.

S2. Monthly data

Table S1. Monthly data, natural lagooning, 2015 (concentrations in mg/L).

Month	Flow in (m³/d)	BOD5 in	BOD5 out	COD in	COD out	TSS in	TSS out	Electricity (kWh/month)
Jan	2,850	440	125	810	259	407	105	7,129
Feb	3,619	480	140	830	269	450	137	7,655
Mar	3,043	520	140	1,102	318	335	164	6,626

Month	Flow in (m³/d)	BOD5 in	BOD5 out	COD in	COD out	TSS in	TSS out	Electricity (kWh/month)
Apr	3,894	460	130	1,003	274	485	115	7,253
May	3,205	500	128	950	300	500	125	6,537
Jun	3,258	540	130	912	311	510	140	6,556
Jul	3,586	460	135	853	312	475	160	7,330
Aug	2,810	460	135	885	312	475	160	6,329
Sep	3,288	690	130	986	259	560	149	6,824
Oct	2,944	460	150	791	344	443	173	6,503
Nov	2,718	496	94	1,063	171	428	152	6,135
Dec	2,754	530	118	1,011	442	468	152	6,728

Flow: monthly mean of daily values estimated from pump operating hours (zero-flow days included). pH, EC, DO and effluent flow were not measured in 2015.

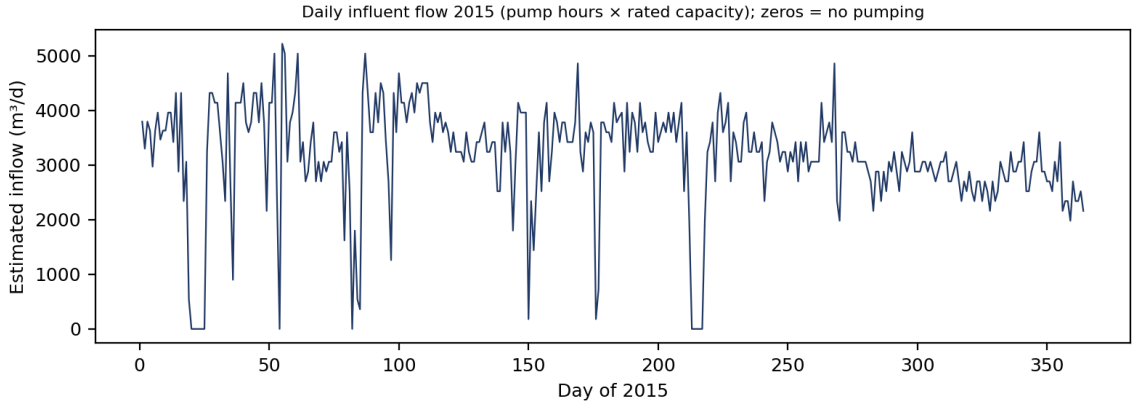


Fig. S5. Daily influent flow in 2015, estimated from pump operating hours × rated pump capacity. Zero values are days without pumping.

Table S2. Monthly data, aerated lagooning, 2024. Q: flow (m³/d); BOD5, COD, TSS, DO: mg/L; EC: µS/cm; kWh/month: total electricity.

Month	Q in	Q out	pH in	pH out	BOD5 in	BOD5 out	COD in	COD out	TSS in	TSS out	EC in	EC out	DO in	DO out	kWh/month
Jan	3,658	2,771	7.73	7.53	460	74	850	152	270	172	4,240	4,010	2.80	9.00	106,917
Feb	3,805	2,891	7.48	7.38	480	65	558	98	340	225	4,300	3,750	2.00	7.50	100,283
Mar	3,974	2,873	7.35	7.40	575	90	660	145	310	196	4,540	3,770	3.00	8.18	106,254
Apr	3,747	3,194	7.54	7.42	540	50	801	120	375	180	4,220	3,760	1.00	8.50	102,705
May	4,564	2,999	7.82	7.74	340	50	772	192	325	120	4,230	4,010	2.05	7.65	107,427
Jun	3,367	3,527	7.89	7.83	540	40	744	114	300	85	4,260	3,870	1.00	9.40	101,877
Jul	3,914	3,272	7.98	7.86	480	45	870	192	370	190	4,150	4,060	1.22	7.37	106,739
Aug	4,402	2,943	7.95	7.87	400	30	560	96	230	110	4,200	4,080	2.00	7.00	107,610
Sep	4,226	2,910	7.92	8.05	500	45	665	195	310	110	4,210	3,950	2.68	9.10	104,637
Oct	4,266	3,160	8.00	7.90	340	25	520	126	235	125	3,650	3,640	2.97	7.75	108,909
Nov	4,050	3,169	8.02	7.88	360	30	540	130	260	120	4,140	4,250	3.02	8.14	93,032
Dec	3,900	3,100	7.90	7.91	350	40	604	140	270	130	4,230	4,238	2.95	8.44	91,011

S3. Treatment performance and compliance

Table S3. Descriptive statistics of monthly values (n = 12 per year). Concentrations in mg/L unless stated; n.m.: not measured.

Variable	2015 mean ± SD	2015 95% CI	2015 min–max	2024 mean ± SD	2024 95% CI	2024 min–max
Influent flow (m³/d)	3,164 ± 381	2,922–3,406	2,718–3,894	3,989 ± 336	3,776–4,203	3,367–4,564
Influent BOD5 (mg/L)	503.0 ± 67.0	460.5–545.5	440.0–690.0	447.1 ± 85.8	392.6–501.6	340.0–575.0
Effluent BOD5 (mg/L)	129.6 ± 13.9	120.8–138.4	94.0–150.0	48.7 ± 19.2	36.5–60.9	25.0–90.0
Influent COD (mg/L)	933.0 ± 102.1	868.2–997.8	791.0–1,102.0	678.7 ± 125.4	599.0–758.4	520.0–870.0
Effluent COD (mg/L)	297.6 ± 63.5	257.2–338.0	171.0–442.0	141.7 ± 35.2	119.3–164.0	96.0–195.0
Influent TSS (mg/L)	461.3 ± 56.5	425.5–497.2	335.0–560.0	299.6 ± 48.1	269.0–330.2	230.0–375.0
Effluent TSS (mg/L)	144.3 ± 20.7	131.2–157.5	105.0–173.0	146.9 ± 43.5	119.2–174.6	85.0–225.0
BOD5 removal (%)	73.9 ± 4.3	71.1–76.6	67.4–81.2	89.2 ± 3.3	87.1–91.3	83.9–92.6
COD removal (%)	67.7 ± 7.5	62.9–72.5	56.3–83.9	78.9 ± 4.4	76.1–81.8	70.7–85.0
TSS removal (%)	68.1 ± 7.2	63.6–72.7	51.0–76.3	51.0 ± 11.7	43.5–58.4	33.8–71.7
Effluent flow (m³/d)	n.m.			3,067 ± 211	2,933–3,202	2,771–3,527
Influent pH	n.m.			7.80 ± 0.22	7.66–7.94	7.35–8.02
Effluent pH	n.m.			7.73 ± 0.23	7.58–7.88	7.38–8.05
Influent EC (µS/cm)	n.m.			4,198 ± 200	4,070–4,325	3,650–4,540
Effluent EC (µS/cm)	n.m.			3,949 ± 195	3,825–4,073	3,640–4,250
Influent DO (mg/L)	n.m.			2.22 ± 0.80	1.72–2.73	1.00–3.02
Effluent DO (mg/L)	n.m.			8.17 ± 0.75	7.69–8.64	7.00–9.40

In 2024, effluent BOD5 and COD complied with the discharge limits in all twelve months, compared with 2 and 1 months respectively in 2015 (Table S4). Effluent TSS exceeded the 150 mg/L limit in 5 of 12 months in 2024 (maximum 225 mg/L), against 6 of 12 months in 2015. Mean effluent TSS did not differ between the two years (Table S5, $p = 0.855$).

The lower TSS removal efficiency in 2024 therefore results mainly from a lower influent TSS concentration (461 → 300 mg/L, $p < 0.001$), not from a deterioration of effluent quality. Influent COD was also significantly lower in 2024, while influent BOD5 did not differ significantly ($p = 0.090$). Efficiency comparisons between the two years should be read in light of these differences in influent composition.

Table S4. Compliance with discharge limit values (ELV) and alternative efficiency calculations.

Parameter	ELV (mg/L)	2015 compliant months	2015 max (mg/L)	2024 compliant months	2024 max (mg/L)	Removal on annual means 2015 / 2024 (%)	Load-based removal 2024 (%)
BOD5	120	2/12	150	12/12	90	74.2 / 89.1	91.7
COD	250	1/12	442	12/12	195	68.1 / 79.1	83.9
TSS	150	6/12	173	7/12	225	68.7 / 51.0	62.3

Compliant months: monthly effluent concentration ≤ ELV. 'Removal on annual means' applies Eq. 1 to the annual mean concentrations. Load-based removal = (Qin·Cin − Qout·Cout)/(Qin·Cin), using the measured effluent flow (2024 only).

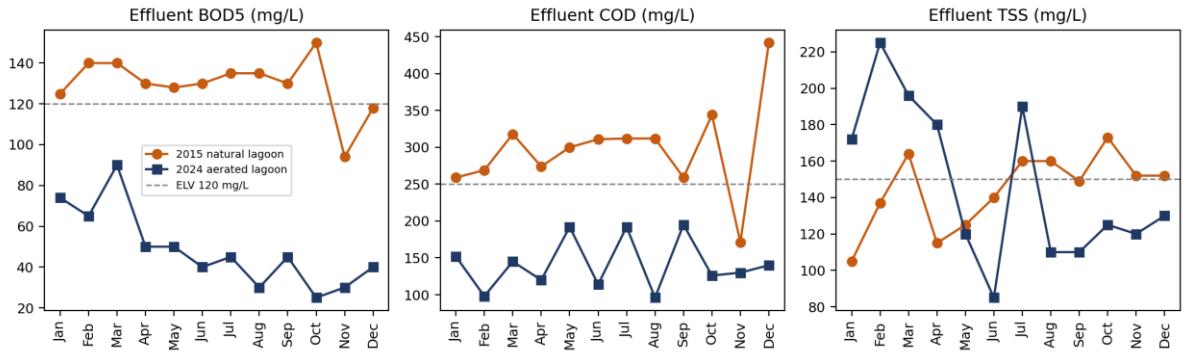


Fig. S1. Monthly effluent BOD5, COD and TSS in 2015 (natural lagoon) and 2024 (aerated lagoon), with the discharge limit values (dashed lines).

S4. Between-year comparison

Table S5. Comparison of monthly values between 2015 and 2024 (difference = 2024 − 2015).

Variable	Mean 2015	Mean 2024	Difference (95% CI)	Welch t	p (Welch)	p (Holm)	p (Mann–Whitney)	Hedges g
Influent BOD5 (mg/L)	503.0	447.1	-55.9 (-121.3 to 9.4)	-1.78	0.090	0.179	0.296	-0.70
Effluent BOD5 (mg/L)	129.6	48.7	-80.9 (-95.2 to -66.7)	-11.83	<0.001	<0.001	<0.001	-4.66
Influent COD (mg/L)	933.0	678.7	-254.3 (-351.4 to -157.3)	-5.45	<0.001	<0.001	<0.001	-2.15
Effluent COD (mg/L)	297.6	141.7	-155.9 (-200.1 to -111.7)	-7.44	<0.001	<0.001	<0.001	-2.93
Influent TSS (mg/L)	461.3	299.6	-161.8 (-206.2 to -117.3)	-7.55	<0.001	<0.001	<0.001	-2.98
Effluent TSS (mg/L)	144.3	146.9	2.6 (-27.0 to 32.1)	0.19	0.855	0.855	0.954	0.07
BOD5 removal (%)	73.9	89.2	15.3 (12.1 to 18.6)	9.72	<0.001	<0.001	<0.001	3.83
COD removal (%)	67.7	78.9	11.3 (6.0 to 16.6)	4.47	<0.001	0.001	<0.001	1.76
TSS removal (%)	68.1	51.0	-17.2 (-25.5 to -8.9)	-4.34	<0.001	0.001	0.001	-1.71
Influent flow (m³/d)	3,164.1	3,989.4	825.3 (520.9 to 1,129.7)	5.63	<0.001	<0.001	<0.001	2.22
Electricity (kWh/d)	224.0	3,381.0	3,157.0 (3,045.1 to 3,269.0)	61.88	<0.001	<0.001	<0.001	24.39
kWh/m³	0.07	0.85	0.78 (0.73 to 0.83)	33.35	<0.001	<0.001	<0.001	13.15

Welch's t-test with 95% CI of the difference; p (Holm): Holm-adjusted across the 12 comparisons; Mann–Whitney U test as non-parametric check; Hedges' g: bias-corrected standardised mean difference.

S5. Energy indicators

Table S6. Electricity consumption and specific energy indicators.

Indicator	2015 (natural lagoon)	2024 (aerated lagoon)
Annual electricity (kWh)	81,605	1,237,401
Annual treated volume (m³)	1,153,039	1,461,063
Electricity, kWh/d (mean ± SD of months)	224 ± 20	3,381 ± 176
Electricity excl. lift station, kWh/d	— (no aeration)	3,151 (93% of total)
kWh/m³ — mean of monthly ratios ± SD (95% CI)	0.071 ± 0.006 (0.068–0.075)	0.853 ± 0.081 (0.801–0.904)
kWh/m³ — ratio of annual totals	0.071	0.847
kWh/kg BOD5 removed — mean ± SD (95% CI)	0.20 ± 0.03 (0.17–0.22)	2.19 ± 0.30 (2.00–2.38)
kWh/kg BOD5 removed — ratio of annual totals	0.19	2.15
kWh/kg COD removed — mean ± SD (95% CI)	0.12 ± 0.03 (0.10–0.13)	1.63 ± 0.27 (1.46–1.80)
BOD5 removed (kg/d, mean)	1,180	1,575
Incremental electricity 2024 vs 2015 (kWh/d)		3,157
Incremental electricity per additional kg BOD5 removed (kWh/kg)		8.0

Indicator	2015 (natural lagoon)	2024 (aerated lagoon)
Electricity cost 2024 at 1.00 / 1.37 MAD/kWh (million MAD/year)		1.24 / 1.70
Electricity cost per m³ at 1.00 / 1.37 MAD/kWh (MAD/m³)		0.85 / 1.16
Incremental electricity cost of the conversion (million MAD/year)		1.15 / 1.58

Specific consumption rose from 0.071 kWh/m³ in 2015, when lift pumping was the only electrical load, to 0.847 kWh/m³ in 2024 (ratio of annual totals; 0.853 ± 0.081 kWh/m³ as mean ± SD of monthly ratios). The conversion added about 3,157 kWh/d for an additional 396 kg/d of BOD5 removed, i.e. about 8.0 kWh per additional kg of BOD5 removed. Part of this additional removal reflects the higher inflow in 2024. At the medium-voltage tariff of about 1.00 MAD/kWh excluding taxes (Royaume du Maroc, 2014), or about 1.37 MAD/kWh including value-added tax and associated charges, the 2024 electricity cost was about 1.24–1.70 million MAD, i.e. 0.85–1.16 MAD/m³ treated. The incremental electricity cost of the conversion is about 1.15–1.58 million MAD per year.

In 2024, daily electricity use was almost independent of flow and organic load (Table S7, Fig. S2). The slope on influent flow was not significant ($p = 0.60$, $R^2 = 0.03$), and the intercept (≈ 3,031 kWh/d) accounts for nearly all consumption. The negative correlation between flow and kWh/m³ reported in the original submission ($r = -0.82$) therefore reflects a near-constant consumption divided by a variable flow, not a load-responsive economy of scale. Effluent dissolved oxygen remained between 7.0 and 9.4 mg/L throughout the year, which suggests that aeration was not modulated to the biological demand. Dissolved-oxygen-based control of the blowers is therefore a potential source of energy savings.

Table S7. Ordinary least-squares regressions of absolute daily electricity consumption (kWh/d).

Model (n = 12)	Intercept a (95% CI)	p(a)	Slope b (95% CI)	p(b)	R^2
2024: E (kWh/d) ~ Q (m3/d)	3,031 (1,577 to 4,485)	<0.001	0.088 (-0.276 to 0.451)	0.603	0.03
2024: E (kWh/d) ~ BOD5 load (kg/d)	2,814 (2,145 to 3,482)	<0.001	0.321 (-0.053 to 0.695)	0.085	0.27
2024: E (kWh/d) ~ BOD5 removed (kg/d)	2,809 (2,128 to 3,491)	<0.001	0.363 (-0.065 to 0.791)	0.088	0.26
2015: E (kWh/d) ~ Q (m3/d)	103 (24 to 181)	0.015	0.038 (0.014 to 0.063)	0.006	0.55

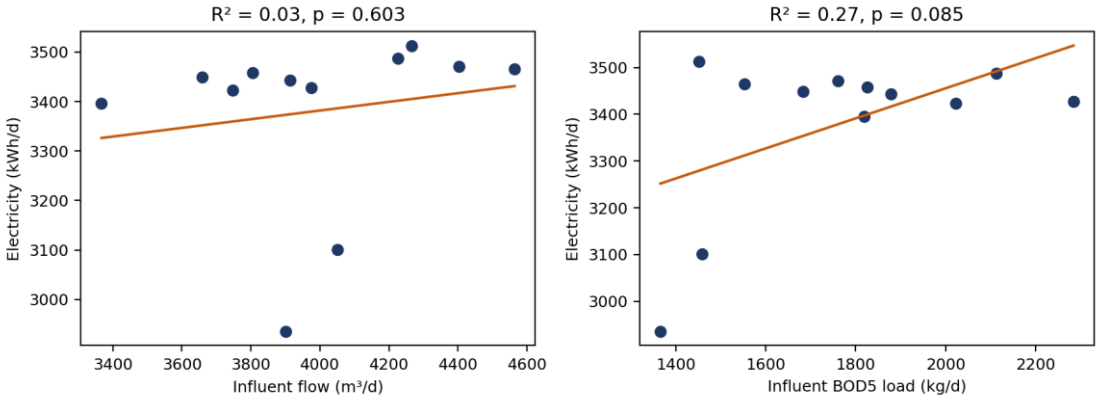


Fig. S2. Daily electricity consumption versus influent flow (left) and influent BOD5 load (right), 2024, with OLS fits.

S6. Correlation analysis

Of the 91 pairs tested for 2024, 16 were significant at $p < 0.05$ before adjustment (Table S8). Only two remained significant after false-discovery-rate control ($q < 0.05$): influent pH–effluent pH, which is trivial, and influent pH–effluent BOD5 ($r = -0.85$, $q = 0.021$). For 2015 (Table S9), only influent flow–electricity was significant before adjustment ($r = 0.74$, $p = 0.006$), consistent with pumping energy that is proportional to the pumped volume; it did not survive FDR control ($q = 0.17$). With $n = 12$, $|r|$ must exceed 0.576 to reach $p < 0.05$, and all correlations are therefore reported as exploratory.

Table S8. Pearson correlations with unadjusted $p < 0.05$, aerated lagoon 2024 ($n = 12$; 91 pairs tested). Full matrix in Fig. S3; all pairs in the S3 output file S_correlations_2024.csv.

Variable X	Variable Y	r	95% CI	p	q (BH)	p (Bonf.)	Spearman ρ	p (ρ)	Shapiro–Wilk p (X / Y)	Max Cook D (month)
Influent pH	Effluent pH	0.92	0.74 to 0.98	<0.001	0.002	0.002	0.81	0.001	0.041 / 0.046	0.82 (Mar)
Influent pH	Effluent BOD5 (mg/L)	-0.85	-0.96 to -0.54	<0.001	0.021	0.041	-0.87	<0.001	0.041 / 0.253	0.49 (Mar)
Effluent pH	Effluent TSS (mg/L)	-0.78	-0.94 to -0.38	0.003	0.067	0.244	-0.62	0.032	0.046 / 0.281	0.33 (Jul)
Effluent pH	Effluent BOD5 (mg/L)	-0.78	-0.93 to -0.37	0.003	0.067	0.268	-0.76	0.004	0.046 / 0.253	0.63 (Mar)
Influent pH	Effluent TSS (mg/L)	-0.72	-0.92 to -0.26	0.008	0.135	0.712	-0.51	0.089	0.041 / 0.281	0.46 (Jul)
Effluent BOD5 (mg/L)	Influent EC (µS/cm)	0.72	0.24 to 0.91	0.009	0.135	0.811	0.76	0.004	0.253 / 0.003	1.16 (Oct)
Effluent BOD5 (mg/L)	Effluent TSS (mg/L)	0.69	0.19 to 0.90	0.014	0.160	1.000	0.63	0.030	0.253 / 0.281	0.26 (Feb)
Effluent EC (µS/cm)	Electricity (kWh/d)	-0.68	-0.90 to -0.18	0.014	0.160	1.000	-0.40	0.198	0.652 / 0.000	1.09 (Dec)
Influent pH	Influent EC (µS/cm)	-0.64	-0.89 to -0.10	0.026	0.245	1.000	-0.90	<0.001	0.041 / 0.003	0.79 (Oct)
Influent TSS (mg/L)	Influent DO (mg/L)	-0.63	-0.88 to -0.09	0.027	0.245	1.000	-0.54	0.073	0.676 / 0.029	0.56 (Aug)
Influent pH	Influent BOD5 (mg/L)	-0.62	-0.88 to -0.08	0.030	0.245	1.000	-0.54	0.071	0.041 / 0.162	0.16 (Jun)
Influent COD (mg/L)	Influent TSS (mg/L)	0.62	0.07 to 0.88	0.032	0.245	1.000	0.60	0.039	0.265 / 0.676	0.71 (Jan)
Influent BOD5 (mg/L)	Effluent BOD5 (mg/L)	0.60	0.04 to 0.87	0.039	0.246	1.000	0.51	0.090	0.162 / 0.253	0.63 (Mar)
Influent flow (m³/d)	Influent BOD5 (mg/L)	-0.60	-0.87 to -0.04	0.040	0.246	1.000	-0.55	0.065	0.999 / 0.162	0.15 (Mar)
Influent flow (m³/d)	Effluent DO (mg/L)	-0.59	-0.87 to -0.03	0.042	0.246	1.000	-0.55	0.063	0.999 / 0.891	0.33 (Sep)
Influent BOD5 (mg/L)	Influent EC (µS/cm)	0.59	0.02 to 0.87	0.043	0.246	1.000	0.51	0.091	0.162 / 0.003	1.04 (Oct)

Table S9. Pearson correlations with unadjusted $p < 0.05$, natural lagoon 2015 ($n = 12$; 28 pairs tested).

Variable X	Variable Y	r	95% CI	p	q (BH)	p (Bonf.)	Spearman ρ	p (ρ)	Shapiro–Wilk p (X / Y)	Max Cook D (month)
Influent flow (m³/d)	Electricity (kWh/d)	0.74	0.29 to 0.92	0.006	0.170	0.170	0.78	0.003	0.349 / 0.056	0.90 (Feb)

Table S10. Re-evaluation of the correlations reported in the original submission.

Year	Pair (as in original submission)	r originally reported	r recomputed	p	Status
2015	Influent BOD5 (mg/L) ↔ BOD5 removal (%)	+0.73	+0.73	0.007	Mathematically coupled — withdrawn
2015	Influent TSS (mg/L) ↔ TSS removal (%)	+0.72	+0.72	0.008	Mathematically coupled — withdrawn
2015	BOD5 removal (%) ↔ Influent COD (mg/L)	+0.66	+0.66	0.019	Retained as exploratory

Year	Pair (as in original submission)	r originally reported	r recomputed	p	Status
2024	Influent BOD5 (mg/L) ↔ kWh/kg BOD5 removed (labelled "influent BOD5/flow ratio" in the original submission)	-0.87	-0.87	<0.001	Mathematically coupled — withdrawn
2024	Influent pH ↔ Effluent BOD5 (mg/L)	-0.85	-0.85	<0.001	Retained as exploratory
2024	Effluent TSS (mg/L) ↔ TSS removal (%)	-0.83	-0.83	<0.001	Mathematically coupled — withdrawn
2024	Influent flow (m³/d) ↔ kWh/m³	-0.82	-0.82	0.001	Mathematically coupled — withdrawn
2024	Influent BOD5 (mg/L) ↔ kWh/m³	+0.75	+0.75	0.005	Ratio-based; replaced by regression of absolute energy (Table S7)
2024	Influent pH ↔ Effluent TSS (mg/L)	-0.72	-0.72	0.008	Retained as exploratory
2024	Effluent BOD5 (mg/L) ↔ Influent EC (µS/cm)	+0.72	+0.72	0.009	Retained as exploratory
2024	Influent TSS (mg/L) ↔ Influent DO (mg/L)	-0.63	-0.63	0.027	Retained as exploratory

Mathematically coupled pairs share a term by construction (the same concentration enters both variables, or one variable is a ratio of the other), so their correlation is partly or wholly artefactual (Pearson, 1897).

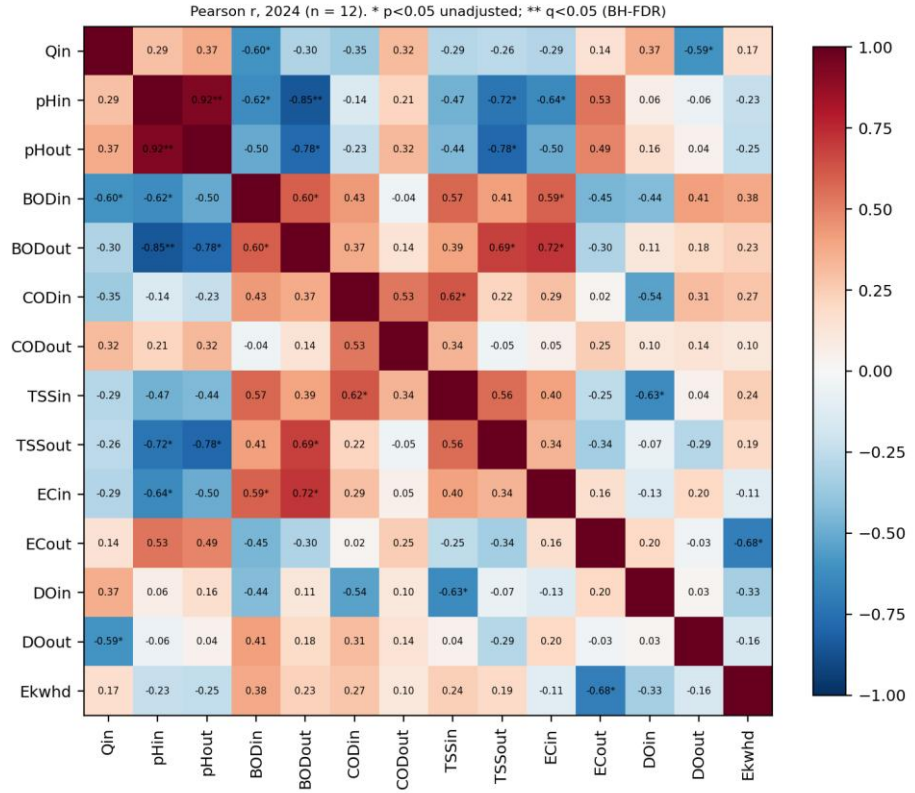


Fig. S3. Pearson correlation matrix, 2024 (n = 12). * p < 0.05 unadjusted; ** q < 0.05 (Benjamini–Hochberg). Qin: influent flow; BOD, COD, TSS, EC, DO, pH: in = influent, out = effluent; Ekwhd: electricity (kWh/d).

S7. Influent pH and effluent BOD5: exploratory check

The association between influent pH and effluent BOD5 in 2024 (r = −0.85, 95% CI −0.96 to −0.54) is partly seasonal. Influent pH increased over the year (r with month index = 0.77, p = 0.004), while effluent BOD5 decreased (r = -0.80, p = 0.002) (Fig. S4). After controlling for the month index, the partial correlation weakened to -0.61 (p = 0.034).

A simple linear model evaluated by leave-one-out cross-validation gave an RMSE of 11.9 mg/L, against 20.1 mg/L for a model using only the mean. This is an internal validation on a single year; it provides no estimate of sensitivity or specificity for an alarm threshold. Influent pH is therefore not proposed as a predictive or alarm indicator. Validation on independent data is required.

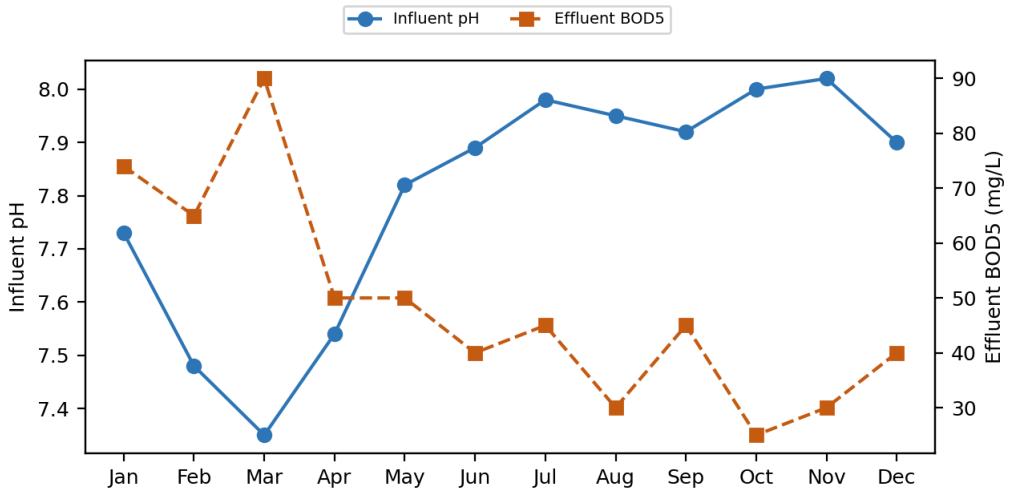


Fig. S4. Monthly influent pH and effluent BOD5, 2024.

S8. Salinity of the treated effluent

Mean effluent electrical conductivity in 2024 was 3.95 dS/m (range 3.64–4.25 dS/m). According to Ayers & Westcot (1985), irrigation water with EC above 3.0 dS/m falls in the 'severe restriction on use' class. The Moroccan irrigation water-quality standards (Arrêté conjoint n° 1276-01, 2002) set a limit value of 12 mS/cm, but likewise indicate that severe restrictions apply above 3 mS/cm. Table S11 gives the leaching requirement for several target soil-salinity levels, using LR = ECw/(5·ECe − ECw) (Ayers & Westcot, 1985).

Microbiological indicators (E. coli, faecal coliforms, helminth eggs), sodium, calcium and magnesium (for SAR), chloride, boron, nutrients and trace elements were not available for the study period. Irrigation suitability therefore cannot be established from these data.

Table S11. Leaching requirement for the 2024 effluent (ECw = 3.95 dS/m).

Target soil salinity ECe (dS/m)	Leaching requirement LR = ECw/(5·ECe − ECw)
4	0.25
6	0.15
8	0.11
10	0.09

S9. Data and code availability

Supplementary Data S2 (Supplementary_Data_S2_Mrirt_WWTP.xlsx) contains the daily 2015 flow records, the monthly 2015 and 2024 data (input values in blue) and all derived indicators as Excel formulas. Supplementary Code S3 (Supplementary_Code_S3_analysis.py) reads S2 and writes all

tables (CSV/JSON) and figures reported here. Command: python Supplementary_Code_S3_analysis.py Supplementary_Data_S2_Mrirt_WWTP.xlsx outputs/. The data are published with the authorisation of ONEE – Water Branch.

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