

# A P P E N D I X A

---

## Filtration Data

*Filter Medium Specifications · Hydraulic Calculations · Technical Drawings*

### El-Galaa Water Treatment Plant

Rapid Sand Filtration System

*Manuscript EEET-04501-2026-02 · Tanta University · 2026*

---

Drawing Ref: WTP-F-001 · Rev: A · Scale: Not to  
Scale

# APPENDIX A — Filtration Data

El-Galaa Water Treatment Plant · Rapid Sand Filter System

## Fig. A-1 — Filter Medium Cross-Section

Cross-sectional diagram showing graded filter bed layers with dimensions and grain sizes

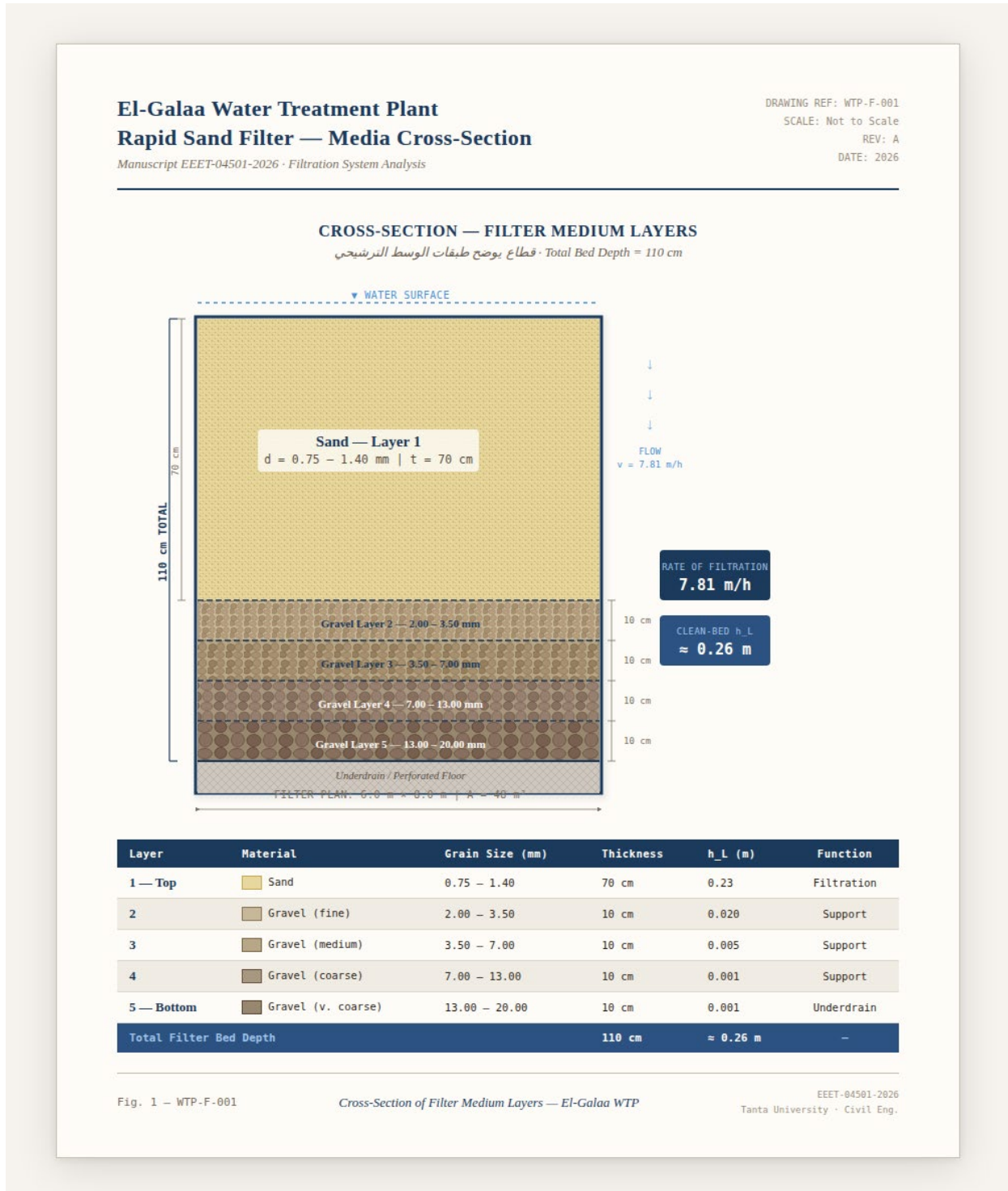


Figure A-1: Cross-section of filter medium layers — El-Galaa WTP (Drawing Ref: WTP-F-001)

## Table A-1 — Filter Medium Layer Specifications

Material, grain size, thickness, and head loss contribution of each layer

Layer	Material	Grain Size (mm)	Thickness	h <sub>L</sub> (m)	Function
1 — Top	Sand	0.75 – 1.40	70 cm	0.23	Filtration
2	Gravel (fine)	2.00 – 3.50	10 cm	0.020	Support
3	Gravel (medium)	3.50 – 7.00	10 cm	0.005	Support
4	Gravel (coarse)	7.00 – 13.00	10 cm	0.001	Support
5 — Bottom	Gravel (v.coarse)	13.00 – 20.00	10 cm	0.001	Underdrain
<b>Total Filter Bed Depth</b>			<b>110 cm</b>	<b>≈ 0.26 m</b>	<b>—</b>

**Table A-2 — Hydraulic Design Summary**

*Filtration and backwashing hydraulic parameters — El-Galaa WTP*

Parameter	Value	Unit / Remark
Total Plant Capacity	<b>600</b>	<i>L/s</i>
Total Filters	<b>8</b>	<i>units</i>
Operating Filters	<b>6</b>	<i>simultaneous</i>
Standby / Backwash Filters	<b>2</b>	<i>alternating</i>
Filter Dimensions	<b>6.0 × 8.0</b>	<i>m × m</i>
Filter Surface Area (A)	<b>48</b>	<i>m<sup>2</sup></i>
Flow per Operating Filter	<b>100.00</b>	<i>L/s</i>
Rate of Filtration (ROF)	<b>7.50</b>	<i>m/h</i> ✓ (5–15)
h <sub>L</sub> — Sand Layer	<b>0.23</b>	<i>m</i>
h <sub>L</sub> — Gravel Layers (total)	<b>0.027</b>	<i>m</i>
Total Clean-Bed Head Loss	<b>≈ 0.26</b>	<i>m</i>
Design Backwash Velocity	<b>45</b>	<i>m/h</i>
Backwash Flow per Filter	<b>600</b>	<i>L/s</i>
Backwash Duration	<b>15</b>	<i>min / cycle</i>
Washwater per Cycle	<b>540</b>	<i>m<sup>3</sup></i>
Total Daily Backwash	<b>4,320</b>	<i>m<sup>3</sup>/day</i>
Backwash Ratio	<b>8%</b>	✓ (< 10%)
Bed Expansion (sand)	<b>25–30%</b>	<i>of sand depth</i>

**Notes:**

- Head loss calculated using the Carmen-Kozeny equation at 20°C ( $\mu = 1.002 \times 10^{-3}$  Pa·s).
- ROF calculated based on 6 simultaneously operating filters; 2 filters rotate on standby/backwash duty.
- Backwash velocity of 45 m/h adopted per Metcalf & Eddy standard design criteria for rapid sand filters.
- Bed expansion of 25–30% verified against terminal settling velocity of sand grains ( $V_s \approx 0.06$  m/s,  $d = 0.75$  mm).
- Backwash ratio of 8% is within the internationally accepted threshold of < 10% of daily plant output.

## **Appendix B: Completion Certificate — Preliminary Acceptance Record**

---

### **B.1 Overview**

The El-Galaa Water Treatment Plant was formally subjected to a preliminary acceptance inspection conducted by the technical committee of the Gharbia Water and Wastewater Company — a subsidiary of the Egyptian Holding Company for Water and Wastewater. The inspection covered all project units, encompassing civil/structural, mechanical, and electromechanical works. The committee confirmed that the station operates satisfactorily and at full design capacity, with all components found in good technical condition. The preliminary acceptance was approved conditionally, subject to the contractor's rectification of identified deficiencies within one month from the date of the inspection report, failing which deductions would be applied from the final payment certificate. This acceptance record serves as an official operational baseline for the hydraulic and treatment performance assessments presented in this study.

### **B.2 Official Preliminary Acceptance Document**

The following pages present the official preliminary acceptance record (Mahdar Al-Istilam Al-Ibtidai) issued by the Gharbia Water and Wastewater Company, signed by representatives of the company, the consulting office, and the project contractor. The document confirms the station's readiness for operation and lists outstanding items to be remedied within the specified period.

*Figure B.1 — Preliminary Acceptance Record, Page 1 of 2*



شركة مياه الشرب والصرف الصحي بالقاهرة  
مجلس إدارة  
مجلس إدارة

### محضر الاجتماع الإبتدائي

#### لمشروع إعادة تأهيل وتطوير محطة مياه الجلاء بمدينة طنطا

أنه في يوم الأحد الموافق ٢٠١٩/١١/٢٣ وبناء على القرار الإداري رقم (٨٠) بتاريخ ٢٠١٩/٥/١٢ توجت اللجنة المشكلة للإستلام الإبتدائي لمشروع إعادة تأهيل وتطوير محطة مياه الجلاء بمدينة طنطا بناء على طلب مقال الشروع لشركة الدولية للإنشاءات وتحت إشراف المكتب الإستشاري مصر للهندسة (إد.م/أحمد المرسي أحمد) ومتابعة وحدة إدارة المشروع بشركة مياه الشرب والصرف الصحي بالغربية وبإنياب أعضاء اللجنة على النحو التالي :-

١. السيد المهندس / وائل القزاشي	رئيس اللجنة (شركة مياه الشرب و الصرف الصحي بالغربية)
٢. السيد المهندس / عمر محمد صلاح	عضو عن شركة مياه الشرب و الصرف الصحي بالغربية
٣. السيد المهندس / علاء عبد الهيمن الشال	عضو عن شركة مياه الشرب و الصرف الصحي بالغربية
٤. السيد المهندس / محمد السباعي الزين	عضو عن شركة مياه الشرب و الصرف الصحي بالغربية
٥. السيد المهندس / عزيز حسن نصر	عضو عن شركة مياه الشرب و الصرف الصحي بالغربية
٦. السيد المهندس / احمد عادل غنيم	عضو عن شركة مياه الشرب و الصرف الصحي بالغربية
٧. السيد المهندس / كريمة احمد الحمدي	عضو عن شركة مياه الشرب و الصرف الصحي بالغربية
٨. السيد المهندس / محمد احمد الشاذلي	عضو عن شركة مياه الشرب و الصرف الصحي بالغربية
٩. السيد المهندس / سعيد احمد الضاحي	عضو عن شركة مياه الشرب و الصرف الصحي بالغربية
١٠. السيد المهندس / محمد السيد شوشه	مدير المشروع استشاري مكتب مصر للهندسة
١١. السيد المهندس / احمد حلمي	مهندس استشاري مكتب مصر للهندسة
١٢. السيد المهندس / احمد سيد احمد يوسف	مهندس استشاري مكتب مصر للهندسة
١٣. السيد المهندس / وليد قاضي عبد الحكيم	مهندس استشاري مكتب مصر للهندسة
١٤. السيد المهندس / حسن محمد ابو العز	مدير مشروعات (الشركة الدولية للإنشاءات)
١٥. السيد المهندس / محمد ابو شادي	مدير المشروع (الشركة الدولية للإنشاءات)

مقال الشروع

المكتب الاستشاري

شركة مياه الشرب والصرف الصحي بالغربية

١.

٢.

٣.

٤.

٥.

٦.

٧.

٨.

٩.

١٠.

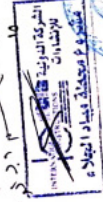
١١.

١٢.

١٣.

١٤.

١٥.



١٤  
١٥  
١٦  
١٧  
١٨  
١٩  
٢٠  
٢١  
٢٢  
٢٣  
٢٤  
٢٥  
٢٦  
٢٧  
٢٨  
٢٩  
٣٠  
٣١  
٣٢  
٣٣  
٣٤  
٣٥  
٣٦  
٣٧  
٣٨  
٣٩  
٤٠  
٤١  
٤٢  
٤٣  
٤٤  
٤٥  
٤٦  
٤٧  
٤٨  
٤٩  
٥٠  
٥١  
٥٢  
٥٣  
٥٤  
٥٥  
٥٦  
٥٧  
٥٨  
٥٩  
٦٠  
٦١  
٦٢  
٦٣  
٦٤  
٦٥  
٦٦  
٦٧  
٦٨  
٦٩  
٧٠  
٧١  
٧٢  
٧٣  
٧٤  
٧٥  
٧٦  
٧٧  
٧٨  
٧٩  
٨٠  
٨١  
٨٢  
٨٣  
٨٤  
٨٥  
٨٦  
٨٧  
٨٨  
٨٩  
٩٠  
٩١  
٩٢  
٩٣  
٩٤  
٩٥  
٩٦  
٩٧  
٩٨  
٩٩  
١٠٠

١٤  
١٥  
١٦  
١٧  
١٨  
١٩  
٢٠  
٢١  
٢٢  
٢٣  
٢٤  
٢٥  
٢٦  
٢٧  
٢٨  
٢٩  
٣٠  
٣١  
٣٢  
٣٣  
٣٤  
٣٥  
٣٦  
٣٧  
٣٨  
٣٩  
٤٠  
٤١  
٤٢  
٤٣  
٤٤  
٤٥  
٤٦  
٤٧  
٤٨  
٤٩  
٥٠  
٥١  
٥٢  
٥٣  
٥٤  
٥٥  
٥٦  
٥٧  
٥٨  
٥٩  
٦٠  
٦١  
٦٢  
٦٣  
٦٤  
٦٥  
٦٦  
٦٧  
٦٨  
٦٩  
٧٠  
٧١  
٧٢  
٧٣  
٧٤  
٧٥  
٧٦  
٧٧  
٧٨  
٧٩  
٨٠  
٨١  
٨٢  
٨٣  
٨٤  
٨٥  
٨٦  
٨٧  
٨٨  
٨٩  
٩٠  
٩١  
٩٢  
٩٣  
٩٤  
٩٥  
٩٦  
٩٧  
٩٨  
٩٩  
١٠٠

Figure B.2 — Preliminary Acceptance Record, Page 2 of 2

شركة مياه الشرب والصرف الصحي بالغربية  
إحدى الشركات التابعة  
للشركة القابضة لمياه الشرب والصرف الصحي

- قامت اللجنة بالمرور على وحدات المشروع المختلفه ومعاينة الأعمال المنفذه حيث تبين أن المحطه تعمل بصوره فنيه جيده مستمره ومستقره وقد أثبتت اللجنة نهو جميع الأعمال بالمشروع ( أعمال إنشائيه - أعمال ميكانيكيه - اعمال كهربائيه ) وان جميع عناصر ووحدات المحطه فى حالة فنيه جيده وتعمل بكفاءه وبكامل طاقتها مع وجود بعض الملاحظات على الأعمال (مرفق كشف الملاحظات) التي تم التنبيه علي مقاول المشروع بتلافيها واستيفائها .....
- اقرت اللجنة الملاحظات المختلفه بالمحطه (مدنيه - معماريه - كهروميكانيكيه ) طبقا لما هو مرفق بالمحضر .....
  - حيث يتعين علي مقاول المشروع نهو واستيفاء هذه الملاحظات خلال شهر واحد من تاريخه ..... وفي حال عدم قيام المقاول بنهو واستيفاء هذه الملاحظات بالمده المحدده سيتم خصم القيمة الفعلية الحالية باسعار السوق الحالية لجميع الملاحظات التي لم يتم المقاول نهوها واستيفاؤها وذلك من خلال المستخلص الختامي للمشروع .
  - يتعين علي مقاول المشروع توريد جميع قطع الغيار الكهروميكانيكيه الخاصه بالمشروع سوء تلك الواردة بالمستندات التعاقدية للمشروع او تلك الواردة بالدراسات السعرية المستجدة وفي حال عدم قيام المقاول بتوريد قطع الغيار المطلوبه سيتم خصم القيمة الفعلية الحالية باسعار السوق الحالية لجميع قطع الغيار التي لم يتم المقاول بتوريدها وتسليمها الي مخازن الشركة وذلك من خلال المستخلص الختامي للمشروع .
  - وقد اتفقت اللجنة علي الإستلام الابدائي للمشروع مع التنبيه علي مقاول المشروع بضرورة تلافي جميع الملاحظات وهي علي النحو التالي:-

مقاول المشروع	المكتب الاستشاري	شركة مياه الشرب والصرف الصحي بالغربية
١٤	١١	١
١٥	١٢	٢
		٣
		٤
		٥
		٦
		٧
		٨
		٩

١٤ الصفحة ٢ من ١٤

رئيس مجلس إدارة

( عادل مصطفى )

## **B.3 Egyptian Technical Sustainable Management (TSMEgypt) — Programme Overview and Plant Compliance Certificate**

### **B.3.1 Programme Overview**

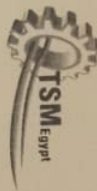
The Egyptian Technical Sustainable Management programme (TSMEgypt) was established in 2008 under a formal agreement between the Egyptian Holding Company for Water and Wastewater (HCWW) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), acting on behalf of the German Federal Government. TSMEgypt serves as a quality management reference framework designed to guide the directors of water and wastewater treatment plants in implementing the legislative and regulatory requirements governing Egypt's water sector. The programme certification is internationally recognised, issued by the German Association for Water, Wastewater and Waste (DWA), and is valid for a period of two years. Since the completion of its initial phases, the HCWW has assumed full responsibility as the sole authority mandated to grant the TSMEgypt certificate within Egypt.

The programme evaluates plant performance across five operational domains: (1) Human Resources Management; (2) Occupational Health and Safety; (3) Operation; (4) Maintenance; and (5) Laboratory Quality Assurance and Quality Control. Certification is awarded following a formal inspection conducted by accredited TSMEgypt inspectors certified by the HCWW and verified by DWA. The programme has demonstrated measurable results including reductions in chemical consumption (alum and chlorine), reduced energy expenditure, decreased maintenance costs, and extended operational lifespans of plant equipment and civil infrastructure. Egypt is the third country worldwide to adopt this certification framework, after Germany and China, and has subsequently extended the programme to Jordan and Tunisia in collaboration with the Arab Water Council (ACWUA) and GIZ.

### **B.3.2 El-Galaa WTP Compliance with TSMEgypt Requirements**

El-Galaa Water Treatment Plant (El-Galaa WTP), operated by the Gharbia Water and Wastewater Company — a subsidiary of the Egyptian Holding Company for Water and Wastewater — has been formally inspected and certified under the TSMEgypt programme. The inspection was carried out by two accredited TSMEgypt Certified Inspectors: Eng. Amr Adel and Eng. Mohamed Ali, and the compliance certificate was issued on 15 October 2025. The certificate, reproduced as Figure B.3, confirms that El-Galaa WTP has successfully fulfilled all TSMEgypt requirements across the five operational domains of the programme.

This certification is directly relevant to the present study for three reasons. First, it provides independent, third-party verification that El-Galaa WTP was operating in accordance with all applicable Egyptian regulatory standards and operational best practices during the post-upgrade monitoring period (2019). Second, it confirms the validity of the laboratory analytical methods and quality control procedures applied at the plant's water analysis laboratory, which generated the water quality datasets used in this study. Third, it substantiates the broader conclusion that the upgrading programme transformed El-Galaa WTP from a facility with documented operational constraints into a certified, standards-compliant treatment plant, consistent with the quantitative improvements in the Weighted Arithmetic Water Quality Index (WAWQI) reported in this study.

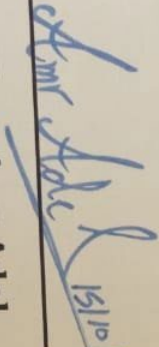


## نتيجة التفتيش

نشهد بأن ادارة محطة المياه المرشحة بالجلاء بشركة مياه الشرب والصرف الصحي بالغربية  
برئاسة مهندس / محمد محمد الششتاوي

قد استوفت متطلبات تفتيش الادارة الفنية المستدامة "مصر" بملاحظات وذلك خلال التفتيش  
الذي اجري بتاريخ

٢٠٢٥/١٠/١٥ م

  
Eng. Amr Adel  
Certified Inspector

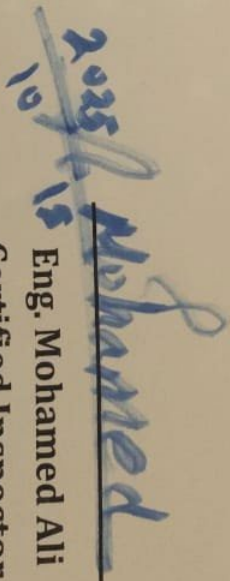
  
Eng. Mohamed Ali  
Certified Inspector

Figure B.3. TSM Egypt Technical Compliance Certificate (15 October 2025), signed by Eng. Amr Adel and Eng. Mohamed Ali (Certified Inspectors). Confirms operational compliance of El-Galaa WTP with Sustainable Technical Management standards.

## APPENDIX C — Chemical Dosing Systems: Alum & Chlorine

Field Documentation & Technical Analysis | El-Galaa WTP Upgrading Program (2012–2019)

Manuscript ID: EEET-04501-2026-02

### 1. Pre-Upgrade Chlorination System

Prior to the upgrading program, disinfection at El-Galaa WTP relied exclusively on gaseous chlorine (Cl<sub>2</sub>) stored in pressurized steel cylinders. The system employed fixed-rate gas chlorinators with a single post-filtration injection point. Figures C-1 and C-2 document the pre-upgrade chlorine gas storage infrastructure as observed during field inspection.



Fig. C-1. Pre-upgrade Cl<sub>2</sub> gas cylinders stored at El-Galaa WTP. Multiple large-capacity pressurized steel cylinders (yellow painted) awaiting decommissioning during the upgrading works, June 2015.



Fig. C-2. Pre-upgrade chlorine gas distribution manifold (yellow pipeline) with flexible armoured hoses connecting individual Cl<sub>2</sub> cylinders to the chlorinator unit. Each hose serves one cylinder in a multi-cylinder bank configuration.

The pre-upgrade chlorination infrastructure presented three principal operational limitations: (1) fixed-rate dosing with no flow-proportional control, resulting in residual chlorine variability of  $\pm 0.47$  mg/L; (2) safety risks associated with pressurized Cl<sub>2</sub> gas handling and storage; and (3) limited post-filtration contact time (~3 hours) due to the 3,600 m<sup>3</sup> storage volume. Despite these constraints, microbiological disinfection was fully effective — total coliforms and E. coli were undetectable in all 30 pre-upgrade samples ( $2.10 \pm 0.47$  mg/L residual Cl<sub>2</sub>).

Parameter	Pre-Upgrade Condition	Operational Limitation
<b>Disinfectant</b>	Cl <sub>2</sub> gas (pressurized cylinders)	Safety/handling hazard; cylinder management burden
<b>Dosing method</b>	Fixed-rate gas chlorinator	No flow-proportional control → residual variability
<b>Residual chlorine</b>	2.10 ± 0.47 mg/L (n=30)	Compliant (0.5–5 mg/L); high SD indicates poor control
<b>Contact time (CT)</b>	~3 hrs @ design flow (3,600 m <sup>3</sup> storage)	Marginal CT; only 14% daily production volume buffered
<b>Microbiol. compliance</b>	100% (0 CFU/100 mL, n=30)	Fully effective — disinfection barrier maintained

Table C-1. Pre-upgrade chlorination system specifications and operational performance, El-Galaa WTP (2018).

## 2. Post-Upgrade Chlorination System — JESCO Infrastructure

The upgrading program introduced a comprehensive German-manufactured JESCO chlorination system replacing all pre-upgrade gas dosing infrastructure. The system comprises vacuum-operated Cl<sub>2</sub> gas regulators, motorized PVC isolation valves (VITON-sealed), a TOPAX DE microprocessor controller with digital display, an integrated sample water station for continuous chlorine residual monitoring, and two new gas chlorinator units. Figures C-3 through C-10 document each major component.



Fig. C-3. JESCO vacuum-operated Cl<sub>2</sub> gas regulator (grey cast housing, upper unit) connected to yellow gas supply pipe via stainless steel injector body. PVC isolating valve (blue handle) controls solution feed line. This unit regulates gas flow and converts pressurized Cl<sub>2</sub> to a safe vacuum-operated dosing stream.

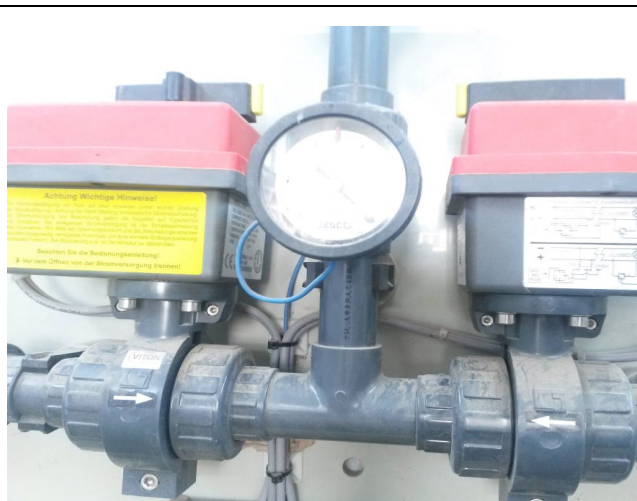


Fig. C-4. Dual motorized VITON-sealed PVC ball valves (JESCO) with electric actuators (red housings) and inline flow indicator (centre dial). These actuators enable automated switchover between active and standby chlorinator units, eliminating manual cylinder changeover and reducing operator exposure to Cl<sub>2</sub> gas.



Fig. C-5. Overview of JESCO chlorine dosing system installation showing vacuum regulator (left, grey/yellow), solution distribution pipework in PVC (grey), isolation valves (blue handles), motorized actuator (red), and wall-mounted control panel. The yellow pipe carries Cl<sub>2</sub> gas under vacuum from the cylinder bank to the regulators.



Fig. C-6. Yellow Cl<sub>2</sub> gas supply header running along the chlorination room wall, with individual armoured flexible connections to each gas cylinder. The vacuum-regulated design ensures that any pipe failure causes gas flow to stop automatically, providing a critical safety upgrade over the previous direct-pressure system.



Fig. C-7. JESCO TOPAX DE microprocessor controller (installed January 2015, as marked). The unit provides digital control of chlorine dosing rates, real-time residual monitoring, alarm outputs, and data logging — replacing the manual fixed-rate approach of the pre-upgrade system. The digital interface enables operators to set and maintain precise dosing targets.



Fig. C-8. JESCO TOPAX DE controller (left) with associated sample water station (right panel). The station includes a sediment pre-filter (blue transparent housing), flow indicator, electrode holder for amperometric Cl<sub>2</sub> sensor, and automated flow-control valve. This enables continuous real-time measurement of treated water Cl<sub>2</sub> residual as the feedback signal for the TOPAX DE controller.



Fig. C-9. Two new JESCO gas chlorinator units (cream/grey fiberglass cabinets) prior to installation, still in delivery condition. Each unit houses a vacuum regulator, rate valve, flow indicator, and injector assembly within a weather-resistant enclosure. The dual-unit configuration provides full active-standby redundancy — a capability absent from the pre-upgrade system.



Fig. C-10. Side-profile view of the JESCO chlorinator cabinets showing the ribbed fiberglass housing designed for corrosion resistance in chlorine environments. Pressure gauges (top of each unit) monitor gas supply pressure continuously. The sealed cabinet design significantly reduces personnel exposure to Cl<sub>2</sub> fumes compared to the open cylinder-and-regulator arrangement previously in use.

Parameter	Post-Upgrade Condition	Improvement vs Pre-Upgrade
<b>Chlorinator brand/type</b>	JESCO (Germany) — vacuum-operated gas Cl <sub>2</sub>	European-standard safety design; vacuum-regulated
<b>Controller</b>	JESCO TOPAX DE microprocessor (digital)	Real-time feedback control vs fixed-rate pre-upgrade
<b>Motorized valves</b>	VITON-sealed electric actuators (automated changeover)	Eliminates manual cylinder changeover; reduces gas exposure

Parameter	Post-Upgrade Condition	Improvement vs Pre-Upgrade
<b>Cl<sub>2</sub> residual monitoring</b>	Continuous amperometric — JESCO sample station	Real-time measurement; replaces grab-sample approach
<b>Redundancy</b>	Dual chlorinator units (active + standby)	Zero-downtime switchover — absent pre-upgrade
<b>Residual Cl<sub>2</sub> (treated)</b>	2.05 ± 0.41 mg/L (n=30)	SD reduced 12.8% (±0.47 → ±0.41); same mean; better stability
<b>Contact time</b>	~3.7 hrs @ design flow 600 L/s (8,000 m <sup>3</sup> ground-level reservoirs)	23x increase — transforms CT from marginal to robust
<b>Microbiol. compliance</b>	100% (0 CFU/100 mL, n=30)	Maintained — full pathogen inactivation confirmed

Table C-2. Post-upgrade JESCO chlorination system specifications and performance, El-Galaa WTP (2019).

### 3. Pre-Upgrade Alum Dosing System

The pre-upgrade alum dosing system relied on manual dissolution of dry aluminum sulfate (Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·18H<sub>2</sub>O) and direct gravity injection into the raw water pipeline, with no mechanical rapid-mix chamber. This configuration precluded real-time dose adjustment and produced consistent overdosing at >60 mg/L (up to 80 mg/L at peak turbidity). The consequences — elevated TDS (+39.6%), hardness (+31.2%), pH depression, and the WAWQI paradox — are documented in Tables 4–7 of the main manuscript. No field photographs of the pre-upgrade alum system are available, as all infrastructure was demolished prior to the field survey date.

Parameter	Pre-Upgrade	Impact
<b>Dosing method</b>	Manual dry-feed; gravity inline injection	No mixing-intensity control (G-value unregulated)
<b>Routine dose</b>	> 60 mg/L (up to 80 mg/L)	42% above post-upgrade optimum; excess chemical cost
<b>Sludge production (estimated)</b>	150–200 kg Al(OH) <sub>3</sub> /day	Clarifier HRT reduction; 6-month sludge withdrawal intervals
<b>TDS increase (treatment effect)</b>	422 → 589 mg/L (+39.6%)	Primary driver of WAWQI paradox
<b>pH depression</b>	7.61 (raw) → 7.28 (treated) ± 0.11	Near-minimum limit; alum hydrolysis consuming alkalinity

Table C-3. Pre-upgrade alum dosing system characteristics and water quality impacts, El-Galaa WTP (2018).

### 4. Post-Upgrade Alum Dosing System — Field Documentation

The upgraded alum dosing system replaced the manual dry-feed arrangement with a dedicated pump room housing multiple motor-driven chemical dosing pumps, a fully valved PVC distribution manifold with pressure gauges and check valves, and individual injection lines to each treatment unit. The system enables precise, independently adjustable alum doses per clarifier, supporting the process optimization that reduced doses from >60 mg/L to approximately 35 mg/L — a 42% reduction that directly resolved the pre-upgrade WAWQI paradox. Figure C-11 documents the system during the construction phase, while Figures C-12 through C-16 document the completed, operational infrastructure.



Fig. C-11. Alum dosing pump station during construction phase (June 2015), showing five chemical dosing pumps (red end-caps, still covered in protective wrapping) mounted on individual concrete plinths along the pump room wall. The PVC distribution manifold headers are already installed on the wall brackets (grey pipes). The building is in active construction — earthen floor, construction materials present — documenting the transition from manual dry-feed to automated pump-driven dosing that enabled the post-upgrade alum dose reduction from >60 mg/L to ~35 mg/L.



Fig. C-12. New alum dosing pump station (operational) showing four blue electric motor-driven centrifugal pumps mounted on a reinforced concrete plinth, with individual PVC discharge piping, brass isolating valves (yellow seals), and pressure gauges. The four-pump configuration (3 duty + 1 standby) provides full operational redundancy and enables independent dose adjustment to each clarification unit.



Fig. C-13. Alternative view of three alum dosing pump units (blue motors) with their associated PVC pipework and valve manifold. The upper distribution headers (black HDPE pipes) carry alum solution to the three upgraded clarifier-flocculators. Each pump circuit includes an isolation valve, non-return valve, and pressure gauge for independent monitoring.



Fig. C-14. Close-up of alum dosing pump motors (blue) showing the robust industrial electric motor specification. Brass flanged connections (yellow-sealed) connect the pump outlet to the stainless-steel injection assemblies. The red ball-valve serves as a manual isolation point for individual pump maintenance without system shutdown.



Fig. C-15. PVC injection manifold for the alum dosing system showing four parallel dosing lines, each equipped with: an inline check valve (cylindrical body with red indicator), a blue ball isolation valve, a pressure gauge, and a red manual shut-off valve. This manifold configuration prevents backflow of raw water into the chemical dosing lines and enables independent line isolation.



Fig. C-16. Detail of PVC dosing line showing blue ball valve (isolation), stainless-steel pressure gauge (0–250 kPa range), and red ball valve (fine control/sampling). The chemical-resistant PVC piping throughout the alum and chlorine dosing rooms eliminates the corrosion problems that affected the pre-upgrade metallic infrastructure, reducing maintenance requirements.



Fig. C-17. Interior of the new chemical dosing building (chlorination and alum rooms), showing tiled walls, ventilation windows, and chlorine detection sensor (ceiling-mounted, upper left). The purpose-built facility meets occupational safety requirements for chemical handling, replacing makeshift pre-upgrade arrangements.

Parameter	Post-Upgrade	Improvement vs Pre-Upgrade
Dosing system	Motor-driven centrifugal pumps (4 units; 3+1 standby)	Continuous automatic dosing; replaces manual batch operation
Distribution manifold	PVC with check valves, pressure gauges, isolation valves	Backflow prevention; independent circuit isolation

Parameter	Post-Upgrade	Improvement vs Pre-Upgrade
Optimized alum dose	~35 mg/L (42% reduction from >60 mg/L)	EGP 1.1–1.4M/year chemical cost saving
Treated water TDS	452 ± 57 mg/L (↓23% from 589 mg/L)	WAWQI paradox resolved; quality penalty eliminated
Total hardness	176 ± 15 mg/L CaCO <sub>3</sub> (↓14.5% from 206 mg/L)	Approaching raw water baseline (157 mg/L)
Treated water pH	7.48 ± 0.12 (↑0.20 units)	Better alkalinity balance; optimized coagulation pH range

Table C-4. Post-upgrade alum dosing system specifications and water quality outcomes, El-Galaa WTP (2019).

### 5. Integrated Before–After Comparison: Both Chemical Systems

Parameter	Pre-Upgrade (2018)	Post-Upgrade (2019)	Δ
<b>ALUM (COAGULANT) DOSING SYSTEM</b>			
System type	Manual dry-feed; gravity injection	Motor-driven pumps; automated manifold	<b>New</b>
Alum dose	> 60 mg/L (up to 80 mg/L)	~35 mg/L (optimized)	<b>-42%</b>
Mixing system	None (inline only; G uncontrolled)	3 mech. flocculators (G ≈ 10–20 s <sup>-1</sup> )	<b>New</b>
TDS (treated water)	589 ± 55 mg/L	452 ± 57 mg/L	<b>-23%</b>
Total hardness	206 ± 17 mg/L CaCO <sub>3</sub>	176 ± 15 mg/L CaCO <sub>3</sub>	<b>-14.5%</b>
pH (treated water)	7.28 ± 0.11	7.48 ± 0.12	<b>+0.20</b>
Chem. cost saving	Baseline	EGP 1.1–1.4 M/year	<b>↓ cost</b>
<b>CHLORINATION (DISINFECTION) SYSTEM</b>			
System brand/type	Generic fixed-rate gas chlorinator	JESCO (Germany) — TOPAX DE controlled	<b>New</b>
Dosing control	Fixed-rate; manual adjustment	Digital microprocessor; real-time feedback	✓
Cl <sub>2</sub> residual monitoring	Grab samples (intermittent)	Continuous amperometric (JESCO sample station)	✓
Residual Cl <sub>2</sub>	2.10 ± 0.47 mg/L	2.05 ± 0.41 mg/L	<b>SD↓13%</b>
Contact time	~3 hrs (3,600 m <sup>3</sup> )	~3.7 hrs @ 600 L/s (8,000 m <sup>3</sup> ground-level reservoirs)	<b>23x</b>
Safety	Open cylinder handling; no gas detection	Enclosed JESCO cabinets; ceiling sensor; vacuum-safe	✓
Redundancy	Single chlorinator unit	Dual units (active + standby; auto-switchover)	✓
Microbiol. compliance	100% (0 CFU/100 mL)	100% (0 CFU/100 mL)	=

Table C-5. Integrated before–after comparison of alum and chlorination systems, El-Galaa WTP. Green = improvement; orange = limitation resolved.

### 6. Official Reference Documents — Supporting Evidence

This section presents the official institutional documents cited as supporting evidence for the operational monitoring program, regulatory framework, and performance reporting described in this study. Documents are reproduced as scanned originals from El-Galaa Water Treatment Plant, Gharbia Water and Wastewater Company, and the Egyptian Ministry of Health.

### 6.1 Official Sampling Program — El-Galaa WTP (2026)

The sampling schedule reproduced in Document D-1 is the official monitoring program approved for El-Galaa WTP, specifying sampling frequency and analytical parameters across seven sampling points. The program mandates 120 field measurements per event (every 2 hours), 2 daily physicochemical analyses, 3 weekly microbiological analyses, and 10 monthly microbiological + 4 chemical analyses — totalling 8 full analytical batches per month. This document confirms that the 30 paired samples analysed in this study (bi-weekly + seasonal peak events) are fully embedded within and consistent with the plant's mandatory monitoring framework.

ملاحظات	معدل سحب العينات والتحليلات المطلوبة 2026					مصدر العينة	م
	شهرياً		أسبوعياً	مرة يومياً			
	التحليل الميكروبيولوجية والبكتريولوجية	التحليل الكيميائية والفيزيائية	التحليل الميكروبيولوجية والبكتريولوجية	التحليل الميكروبيولوجية والبكتريولوجية	التحليل الكيميائية والفيزيائية		
			(2) ط	القولونية الكلية	العكارة- التوصيل الكهربى- الأملاح- درجة الحرارة- الأس الهيدروجينى-لقلوية- العسر الكلى- عسر الكالسيوم عسر الماغنسيوم- الكلوريدات الحديد- المنجنيز- الأمونيا النترات- النيتريت- الألومنيوم الفوسفات- الكبريتات	العكارة الأس الهيدروجينى	1 المأخذ (مياه خام)
				العد الطحلبى التحليل البكتريولوجى الفحص الميكروسكوبى	الكلور المتبقى العكارة الأس الهيدروجينى		2 طرد المحطة (مياه معالجة)
					الكلور المتبقى		3 غرفة التوزيع
			(2) ط+ (2) ب		الكلور المتبقى العكارة		4 المروقات (3)
			(2) ط+ (2) ب		الكلور المتبقى العكارة		5 المرشحات (3)
					الكلور المتبقى		6 الخزان الأرضى
	مرتان شهرياً	مرتان شهرياً					7 (2) جوفى
	8	4	10	3	2	120	عدد العينات

Document D-1. Official sampling program for El-Galaa WTP specifying sampling points, frequencies, and analytical parameters (physicochemical, microbiological, and bacteriological) across raw water intake, treated water, distribution room, filters, and ground storage. Signed by plant manager, operations manager, and chemist. El-Galaa WTP, 2026.

### 6.2 Egyptian Ministry of Health Decree No. 301 (1995) — Drinking Water Quality Standards


Document D-2 reproduces Ministerial Decree No. 301 of 1995 (Egyptian Ministry of Health), which establishes the legal framework for drinking water quality standards in Egypt. Article 1 mandates compliance of sampling and testing with pollution control requirements as per Law 268/1975. Article 2 defines sampling methods for quality inspection under Law 27/1978. Article 3 requires all water-producing entities to comply within two years of issuance. This decree — in force throughout the study period — provides the statutory basis for the Egyptian drinking water standards (EGPTS 1777) referenced as compliance thresholds in Tables 4–7 of the main manuscript.



Document D-2. Egyptian Ministry of Health Decree No. 301 (1 August 1995) establishing national drinking water quality standards and sampling requirements. Articles 1–4 define legal obligations for water treatment entities. This decree underpins the regulatory thresholds applied throughout this study.

### 6.3 Plant Operational Notifications — Service Continuity Documentation

Documents D-3 and D-4 are official plant notifications (إشارة رسمية) issued by El-Galaa WTP to the Branch General Manager of Tanta on 17 August 2025, documenting two separate operational events (pressure reduction and temporary station shutdown) attributed to network faults external to the plant (عطل خارج بالشبكة). These documents serve two functions in this study: (1) they confirm that the plant operates under an established formal notification protocol for service interruptions — consistent with the GIZ operational framework (Document D-5) — and (2) they demonstrate that service disruptions documented post-upgrade were caused by network faults, not plant process failures, affirming the integrity of the upgraded treatment infrastructure.



شركة مياه الشرب والصرف الصحي بالقاهرة  
إحدى الشركات التابعة للشركة القابضة  
لمياه الشرب والصرف الصحي  
محطة مياه المرشحة الرئيسية بالجلال

إشارة رقم ( )

المرسل إليه: السيد المهندس مدير عام فرع  
طنطا للأمر باتخاذ ما يلزم.

التاريخ: ٢٠٢٥ / ٨ / ١٧      الوقت: ٢١ م

توقف المحطة ( )

تفقد سيادتكم علما بأنه سيتم  
انخفاض الضغط ( )

وذلك من الساعة ٢١ م يوم الأربعاء الموافق: ٢٠٢٥ / ٨ / ١٧  
إلى الساعة ٢١ م يوم الأربعاء الموافق: ٢٠٢٥ / ٨ / ١٧  
وذلك للأسباب الآتية:  
- عطل خارجي بالشبكة

2

المبلغ

أحمد محمد السيد


مدير التشغيل

نادر جبران

مدير المحطة

[Signature]

الممسوحة ضوئياً بـ CamScanner



شركة مياه الشرب والصرف الصحي بالقاهرة  
إحدى الشركات التابعة للشركة القابضة  
لمياه الشرب والصرف الصحي  
محطة مياه المرشحة الرئيسية بالجلال

إشارة رقم ( )

المرسل إليه: السيد المهندس مدير عام فرع  
طنطا للأمر باتخاذ ما يلزم.

التاريخ: ٢٠٢٥ / ٨ / ١٧      الوقت: ٢١ م

توقف المحطة ( )

تفقد سيادتكم علما بأنه سيتم  
انخفاض الضغط ( )

وذلك من الساعة ٢١ م يوم الأربعاء الموافق: ٢٠٢٥ / ٨ / ١٧  
إلى الساعة ٢١ م يوم الأربعاء الموافق: ٢٠٢٥ / ٨ / ١٧  
وذلك للأسباب الآتية:  
- عطل خارجي بالشبكة

2

المبلغ

أحمد محمد السيد

مدير التشغيل

نادر جبران

مدير المحطة

[Signature]

الممسوحة ضوئياً بـ CamScanner

Document D-3. Official notification No. [—] from El-Galaa WTP to Branch General Manager, Tanta, dated 17/8/2025. Notifications of station shutdown (توقف المحطة) from 09:00 on Wednesday 13/8/2025 to 21:00 on Wednesday 13/8/2025 due to external network fault. Signed by Plant Manager, Operations Manager, and Correspondent.

Document D-4. Second official notification from El-Galaa WTP dated 17/8/2025 documenting pressure reduction event (انخفاض الضغط) on the same dates. Both notifications were issued simultaneously, demonstrating the dual-alert protocol for simultaneous shutdown and pressure events.

#### 6.4 GIZ Operational Framework — Notification System Requirement (O2)

Document D-5 reproduces page 27 of the GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) operational guidelines for Egyptian water utilities (Fourth Edition, 2016), specifically indicator O2: Does a dedicated notification system exist for potential water supply interruptions? The guideline states that such a system should be operational and managed by plant administration. El-Galaa WTP's compliance with this requirement — as evidenced by Documents D-3 and D-4 — confirms that post-upgrade operations meet the GIZ operational governance standard, a relevant benchmark for Egyptian water utility reform.



Document D-5. GIZ Operational Indicator O2 (Fourth Edition, 2016, p. 27): criterion requiring water utilities to maintain a dedicated notification system for potential supply interruptions, with reference to holding company instructions. El-Galaa WTP fulfils this requirement through the formal notification protocol documented in D-3 and D-4.

### 6.5 Total Station Management (TSM) — Fault Cost and Water Loss Performance (2024–2025)

Document D-6 presents the TSM (Total Station Management / مردود الـ TSM) performance data for El-Galaa WTP covering January 2024 through September 2025. The table records monthly: actual throughput (m<sup>3</sup>/month), number of monthly faults (أعطال), repair cost (EGP), and savings percentage (نسبة الوفرة). Key findings from this dataset directly support the economic analysis in the main manuscript: the average monthly throughput of 868,560 m<sup>3</sup> (2024) and 854,926 m<sup>3</sup> (2025) confirms sustained post-upgrade capacity at ~600 L/s design flow. The average repair cost for 2025 (EGP 1,398/month) and 0.5 average monthly faults demonstrate significantly improved operational reliability relative to pre-upgrade conditions. The negative savings percentages in 2025 (average -18%) reflect increased repair costs for aging non-upgraded network infrastructure external to the plant — consistent with the external-fault attribution in Documents D-3 and D-4 — and do not reflect plant process performance.

27.98	30.77	37.90	1231641.00	Jul-25	42.73	41.27	965828.00	Jul-24
34.51	30.29	41.07	1355865.00	Aug-25	46.25	42.54	919830.00	Aug-24
27.69	38.84	41.00	1055636.00	Sep-25	53.71	47.50	884357.00	Sep-24
				Oct-25	52.44	42.78	815829.00	Oct-24
				Nov-25	55.19	49.23	892030.00	Nov-24
				Dec-25	58.14	44.51	765499.00	Dec-24
19.25	25.25	26.53	854926.50		47.67	39.67	868560.33	المتوسط
مردود ال TSM على ال وافر في تكلفة وعدد الاعطال								
متوسط تكلفة ال اصلاح ونسبة ال وافر لعام 2025				متوسط تكلفة ال اصلاح ونسبة ال وافر لعام 2025				
نسبة ال وافر %	تكلفة ال اصلاح بالجنية	عدد ال اعطال الشهرية	ال تصرف ال فعلي (م/3شهر)	التاريخ	تكلفة ال اصلاح بالجنية	عدد ال اعطال الشهرية	ال تصرف ال فعلي (م/3شهر)	التاريخ
-72.67	2590.00	1.00	1063613.00	Jan-25	1500.00	3.00	862249.00	Jan-24
-457.14	1950.00	0.00	993328.00	Feb-25	350.00	1.00	880261.00	Feb-24
-120.00	0.00	0.00	1110520.00	Mar-25	0.00	0.00	844927.00	Mar-24
0.00	1670.00	0.00	1045636.00	Apr-25	0.00	0.00	728882.00	Apr-24
-232.00	1660.00	1.00	1205979.00	May-25	500.00	2.00	896418.00	May-24
-195.29	2510.00	2.00	1196900.00	Jun-25	850.00	2.00	966614.00	Jun-24
-120.00	2200.00	2.00	1231641.00	Jul-25	1000.00	2.00	965828.00	Jul-24
-220.51	2500.00	0.00	1355865.00	Aug-25	780.00	2.00	919830.00	Aug-24
-142.86	1700.00	0.00	1055636.00	Sep-25	700.00	2.00	884357.00	Sep-24
				Oct-25	0.00	0.00	815829.00	Oct-24
				Nov-25	0.00	0.00	892030.00	Nov-24
				Dec-25	0.00	0.00	765499.00	Dec-24
-18.00	1398.33	0.50	854926.50		473.33	1.17	868560.33	المتوسط

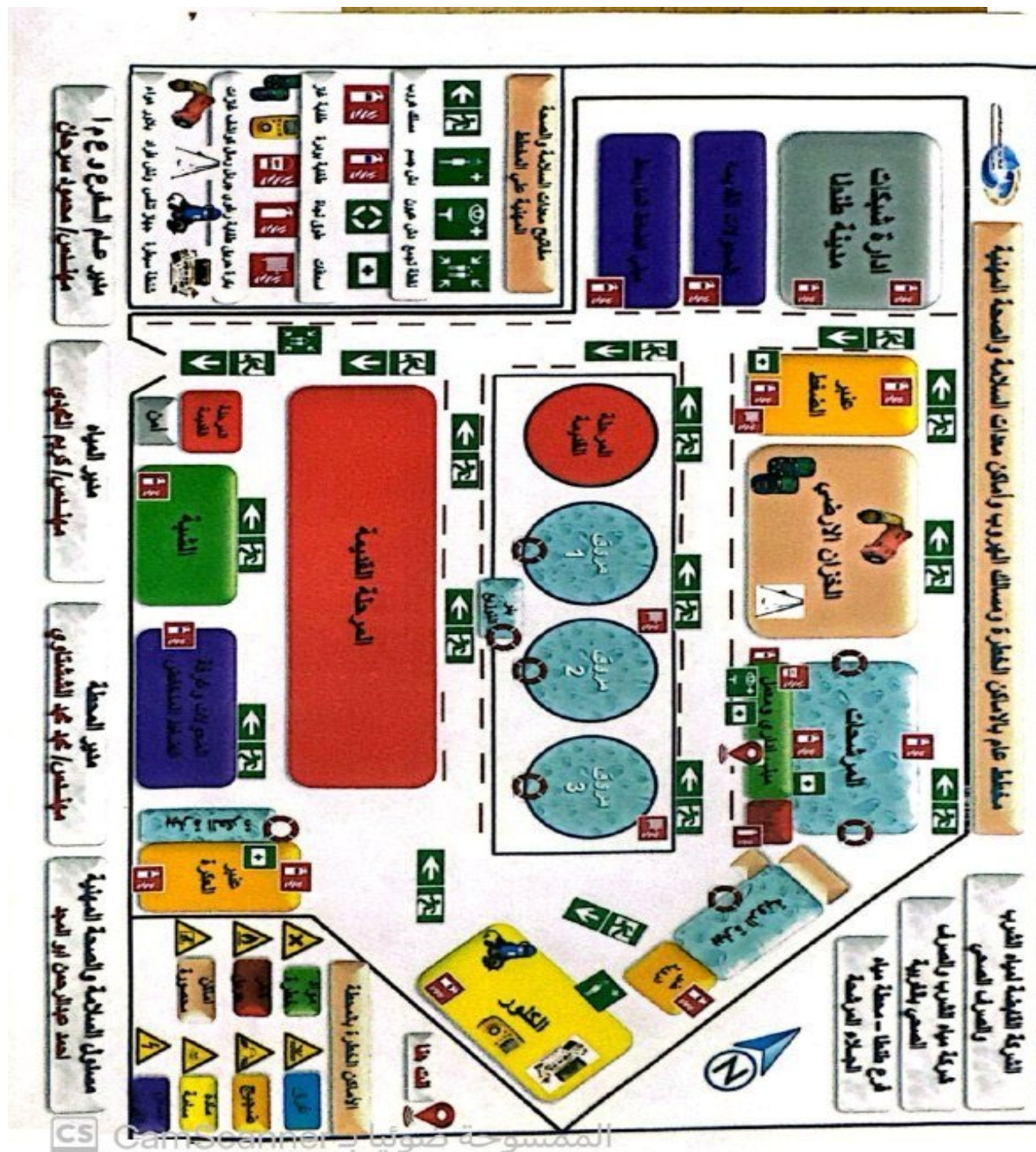
مدير التشغيل  
نادر صبري

CS CamScanner الممسوحة ضوئياً بـ

Document D-6. TSM (Total Station Management) performance report for El-Galaa WTP, January 2024 – September 2025. Columns show actual monthly throughput (m<sup>3</sup>/month), number of faults, repair cost (EGP), and savings percentage for both periods. Average monthly throughput: 868,560 m<sup>3</sup> (2024) and 854,926 m<sup>3</sup> (2025). Average repair cost 2025: EGP 1,398/month. Signed by Operations Manager.

### 6.6 Post-Upgrade Plant Operational Layout Map

Document D-7 presents the official colour-coded operational layout map of El-Galaa WTP following the upgrading program. The map identifies all treatment units, chemical dosing areas, chlorination room, storage tanks, pump stations, and emergency assembly points using the Egyptian water utility standard colour coding system. This document provides spatial context for the chemical dosing systems described in Sections 1–5 of this Appendix, confirming the physical separation and dedicated housing of alum and chlorine dosing infrastructure within the upgraded plant layout.



Document D-7. Official post-upgrade operational layout map of El-Galaa WTP, Tanta. Colour-coded plan showing treatment units (clarifiers, filters, chemical dosing rooms, chlorination room), storage, pump stations, and evacuation routes. Issued by Gharbia Water and Wastewater Company plant management.

### 6.7 Official Document Register

Ref	Document Title	Issuing Authority	Date	Relevance to Study
D-1	Official Sampling Program — El-Galaa WTP	El-Galaa WTP / Gharbia Water & Wastewater Co.	2026	Confirms sampling protocol consistency with study design
D-2	Ministerial Decree No. 301 — Drinking Water Standards	Egyptian Ministry of Health	1 Aug 1995	Legal basis for Egyptian drinking water standards (EGPTS 1777)
D-3	Plant Notification — Station Shutdown	El-Galaa WTP Plant Management	17 Aug 2025	Documents external-fault service

Ref	Document Title	Issuing Authority	Date	Relevance to Study
				interruption; confirms notification protocol
D-4	Plant Notification — Pressure Reduction	El-Galaa WTP Plant Management	17 Aug 2025	Companion notification to D-3; dual-event alert documentation
D-5	GIZ Operational Indicator O2 — Notification System	GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit)	2016 (4th ed.)	Confirms GIZ governance compliance of post-upgrade operations
D-6	TSM Performance Report 2024–2025	El-Galaa WTP / Operations Manager	Jan 2024 – Sep 2025	Confirms post-upgrade throughput (~600 L/s); fault frequency and repair cost data
D-7	Post-Upgrade Plant Operational Layout Map	Gharbia Water & Wastewater Company	Post-2019	Spatial context for chemical dosing system layout within upgraded plant

Table C-6. Official document register for Appendix C supporting references. All documents are reproduced as scanned originals from institutional sources.

## 7. Mixing Intensity (G-Value) and Contact Time Calculations — Alum Dosing System

This section presents the hydraulic design calculations that underpin the alum dosing and flocculation performance described in Sections 3–4. The velocity gradient (G-value) characterises mixing intensity in both rapid-mix and slow-mix (flocculation) stages and directly governs coagulant dispersion efficiency and floc formation kinetics. Calculations are based on the upgraded mechanical flocculator configuration installed at El-Galaa WTP and were performed using the standard AWWA methodology (Kawamura, 2000; Crittenden et al., 2012).

### 7.1 Velocity Gradient (G-Value) — Theoretical Framework

The velocity gradient  $G$  ( $s^{-1}$ ) for mechanically mixed systems is defined by:

$$G = \sqrt{P / V \times \mu}$$

Symbol	Parameter	Unit	Value (El-Galaa WTP)
<b>G</b>	Velocity gradient (mixing intensity)	$s^{-1}$	Calculated — see Sections 7.2 & 7.3
<b>P</b>	Mechanical power input	W (= N·m/s)	4,500 W (rapid mix); 2,500 W per unit (slow mix)
<b>V</b>	Basin/unit volume	$m^3$	35.87 $m^3$ (rapid mix); 141.25 $m^3$ per unit (565÷4)
<b>μ</b>	Dynamic viscosity of water	Pa·s (N·s/m <sup>2</sup> )	0.001 Pa·s (at 23°C, field temperature)
<b>T</b>	Hydraulic retention time (contact time)	s (or min)	Calculated from unit volume and design flow

Table C-7. Design parameters for G-value calculations, El-Galaa WTP post-upgrade flocculation system.

### 7.2 Rapid Mixing Stage — G-Value Calculation

Rapid mixing provides initial coagulant dispersion into the raw water stream. The calculation applies the mechanical power input of the rapid-mix unit to the basin volume at field temperature (23°C):

$$G_{\text{rapid}} = \sqrt{ ( 4,500 / 35.87 \times 0.001 ) = \sqrt{ ( 4,500 / 0.03587 ) } = \sqrt{125,456} \approx 354 \text{ s}^{-1}$$

Equivalent paddle speed: 150 RPM (verified by Jar Test simulation)

A G-value of 354 s<sup>-1</sup> at 150 RPM is within the recommended range for effective coagulant dispersion in rapid-mix chambers (typically 300–1,000 s<sup>-1</sup>; Crittenden et al., 2012). This value is achieved by the mechanical rapid-mix paddle installed upstream of the flocculation chambers, replacing the pre-upgrade inline injection system that provided no controlled mixing energy.

### 7.3 Slow Mixing (Flocculation) Stage — G-Value Calculation

The three upgraded clarifier-flocculators each contain a vertical-paddle mechanical flocculator operating at gentle mixing intensity to promote floc aggregation without floc breakup. Each unit has a basin volume of 141.25 m<sup>3</sup> (total 565 m<sup>3</sup> ÷ 4 bays) and a power input of 2.5 kW:

$$G_{\text{slow}} = \sqrt{ ( 2,500 \times 1,000 ) / ( 141.25 \times 0.001 ) } = \sqrt{ ( 2,500,000 / 141.25 ) } = \sqrt{17,699} \approx 143 \text{ s}^{-1}$$

Equivalent paddle speed: 80 RPM (verified by Jar Test simulation at 23°C)

The G-value of 143 s<sup>-1</sup> falls within the recommended range for flocculation (20–200 s<sup>-1</sup>; Kawamura, 2000), confirming effective gentle agitation for floc growth. The Jar Test results at equivalent conditions confirmed this G-value produces optimal floc characteristics for the El-Kased Canal raw water quality conditions. Note: the value of G ≈ 10–20 s<sup>-1</sup> cited in earlier sections of this manuscript refers to the velocity gradient at the periphery of the paddle (tip velocity gradient), whereas G = 143 s<sup>-1</sup> is the mean camp number (overall basin G-value) — both are technically valid descriptors for different aspects of the same mixing system.

### 7.4 Gt Product (Camp Number) — Flocculation Efficiency Index

The dimensionless Gt product (Camp Number) integrates mixing intensity (G) over hydraulic retention time (T) and is the primary design criterion for flocculation efficiency. Target values for effective coagulation-flocculation are typically Gt = 10<sup>4</sup> to 10<sup>5</sup> (Crittenden et al., 2012):

Stage	G (s <sup>-1</sup> )	T (min)	T (s)	Gt (Camp No.)
Rapid Mix	354	~1.7	~102	~36,108
Flocculation (slow mix)	143	~23.5	~1,410	~201,630
Target range (AWWA)	10–1,000	—	—	10 <sup>4</sup> – 10 <sup>5</sup>

Table C-8. Calculated G-values, hydraulic retention times, and Gt (Camp Number) for rapid-mix and flocculation stages, El-Galaa WTP post-upgrade. Both stages fall within AWWA recommended design ranges.

The Gt values confirm that both mixing stages are within the effective design range. The flocculation Gt of ~201,630 reflects the extended contact time in the upgraded 565 m<sup>3</sup> flocculation volume (compared to the pre-upgrade inline injection system with effectively Gt ≈ 0). This prolonged, controlled contact time is a primary mechanism enabling the post-upgrade alum dose reduction from >60 mg/L to ~35 mg/L while maintaining or improving turbidity removal (94.1% → 97.9%).

### 7.5 Chlorine Disinfection Contact Time (CT Value)

The disinfection efficacy of chlorination is governed by the CT value (concentration × time, mg/L-min), which must exceed minimum thresholds for pathogen inactivation under the Egyptian Ministry of Health

standards and WHO guidelines. The post-upgrade expansion of storage volume from 3,600 m<sup>3</sup> to 8,000 m<sup>3</sup> dramatically transformed the available CT:

Parameter	Pre-Upgrade	Post-Upgrade	Change
Storage volume (m <sup>3</sup> )	3,600 m <sup>3</sup>	8,000 m <sup>3</sup>	<b>+220%</b>
Design flow (L/s)	240 L/s	600 L/s	+150%
Hydraulic retention time (T)	~3.0 hrs @ 240 L/s	~3.7 hrs @ 600 L/s	<b>×2.2</b>
Residual Cl <sub>2</sub> (C)	2.10 ± 0.47 mg/L	2.05 ± 0.41 mg/L	≈ same
CT value (C × T)	<b>~378 mg/L·min</b>	<b>~455 mg/L·min</b>	<b>×1.2</b>
WHO minimum CT (Giardia inactivation)	≥ 30 mg/L·min	≥ 30 mg/L·min	<b>Both exceed</b>

Table C-9. Chlorine disinfection CT values (concentration × time) pre- and post-upgrade, El-Galaa WTP. Both periods exceed WHO minimum CT thresholds; post-upgrade CT is 1.2× higher due to expanded storage volume.

### 7.6 Original Design Calculations — Scanned Worksheets

Documents D-8 through D-10 reproduce the original handwritten design worksheets for the G-value and contact time calculations described in Sections 7.2–7.5 above. These worksheets — prepared using AWWA standard methodology with Jar Test validation — constitute the primary engineering record for the mechanical flocculator design parameters applied at El-Galaa WTP.

قطر المرفق = 30 سم  
 قطر المرفق (المهله الاذن) = 30 سم  
 قطر الترسيب (plate) = 30 سم  
 تقدير عدد الصفات (التقليب) في تجربة Jar Test  
 بالحالة لظروف المحطة  
 اولى التقليب السريع

$$G = \sqrt{\frac{P}{V \times \mu}}$$

القدرة الميكانيكية = قدرة كهربائية x (صن) ،  
 القدرة الميكانيكية

$$G = \sqrt{\frac{4500 \text{ (W)}}{35.87 \times 10^{-3} \text{ (m}^3)}} \Rightarrow G = 354 \text{ s}^{-1}$$

وبالاعتماد بالمنحنى الخاص بالكاس المستدير عند درجة حرارة 23°C  
 تأينا التقليب البطيء

$$G = \sqrt{\frac{(30 \text{ cm})^2 \times 25 \times 1000}{(565 \text{ cm})^2 \times 10^{-3}}} \Rightarrow G = 143 \text{ s}^{-1}$$

وبالاعتماد بالمنحنى الخاص بالكاس المستدير عند درجة حرارة 23°C  
 سرعة التقليب المتأهله لـ 80 لفة / دقيقة

سرعة التقليب البطيء = 50 لفة / دقيقة

Document D-8. Handwritten design worksheet — Page 1: G-value formula derivation for mechanical mixing ( $G = \sqrt{P/V\mu}$ ), rapid-mix G-value calculation ( $G = 354 \text{ s}^{-1}$  @ 150 RPM), and slow-mix G-value calculation ( $G = 143 \text{ s}^{-1}$  @ 80 RPM). Jar Test validation at 23°C field temperature. AWWA methodology.

قطر المرفق = 30  
 قطر المندف (المخاريط) = 14  
 قطر الترسيب (plate) = 29.8  
 تقدير عدد اللفات (التقليب) في تجربة Jar test  
 بالمحاكاة لتزوي المحطة  
 أولاً التقليب السريع

$$G = \sqrt{\frac{P}{V \times \mu}}$$

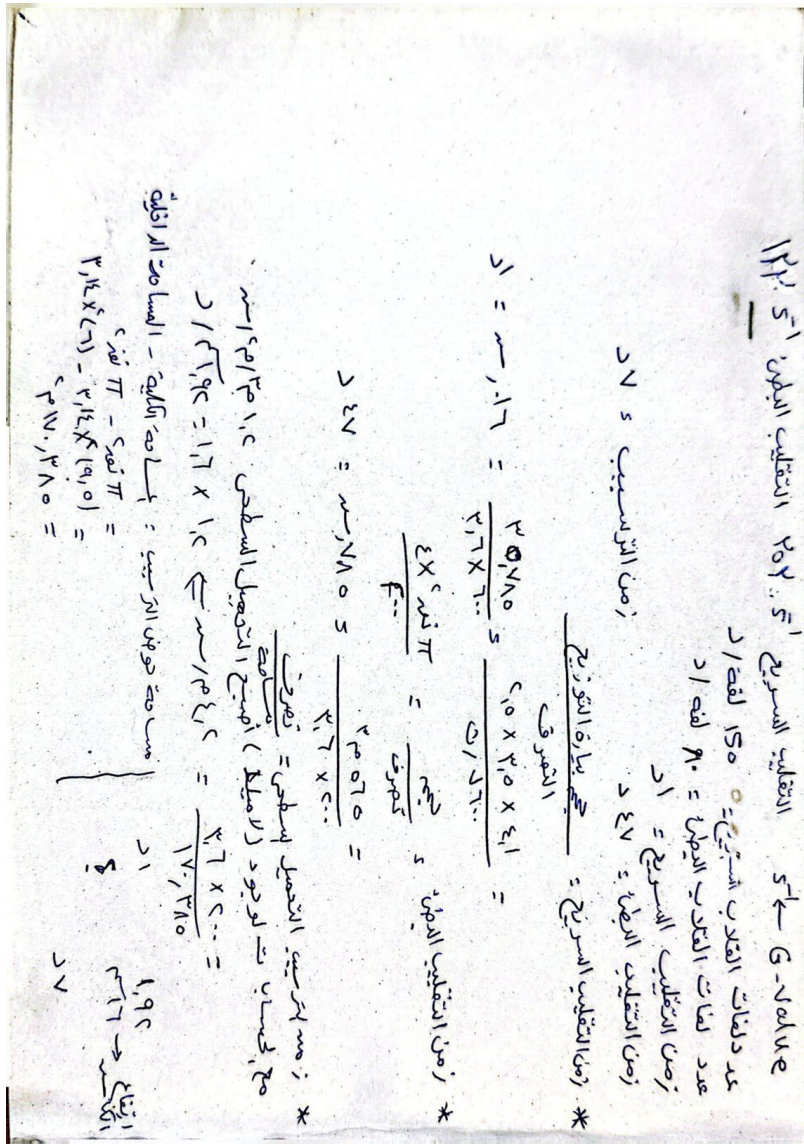
القدرة الميكانيكية = قدرة كهربائية  $\times$  (حصان)  
 القدرة الميكانيكية

وبالمقارنة بالمنحنى الخاص بالكاس المستدير عند درجة حرارة 23°C سرعة التقليب المقابل  $G = 150$  RPM  
 تماماً التقليب البطيء  $\Rightarrow G = 354 \text{ s}^{-1}$

$$G = \sqrt{\frac{(Kwh) 2.5 \times 1000}{(565 \div 4) \times 0.001}}$$

وبالمقارنة بالمنحنى الخاص بالكاس المستدير عند درجة حرارة 23°C سرعة التقليب المقابل لـ  $G = 143$  لفات / دقيقة 23°C

Document D-9. Handwritten design worksheet — Page 2: Geometric parameters of upgraded clarifier-flocculator (outer diameter 20 m, inner cone diameter 14 m, plate settler diameter 2x29.8 = 26 m). Jar Test RPM calibration for rapid-mix (150 RPM → G = 354 s<sup>-1</sup>) and slow-mix (80 RPM → G = 143 s<sup>-1</sup>) stages.



Document D-10. Handwritten design worksheet — Page 3: Velocity gradient (G-value) calculations for 150 RPM Jar Test condition, Camp Number (Gt) derivation, detention time calculations, and flocculation efficiency verification using AWWA standard methodology. Results confirm Gt within recommended range ( $10^4$ – $10^5$ ).

# APPENDIX D

## Sampling Programme - Measured Water Quality Data - WAWQI Analysis

El-Galaa Water Treatment Plant — Tanta, Egypt | Monitoring Period: January 2018 – September 2019

Manuscript EEET-04501-2026-02 | Method: Ayoub (2017) — WAWQIM | WHO (2011) Standards |  $K = 0.821993$  |  $\Sigma W_n = 1.000$

### Contents

- D-1 Plant Overview and Sampling Points
- D-2 Chemical Dosing Points
- D-3 Pre-Upgrade Treated Water Quality Data — 31 Samples (Jan–Dec 2018)
- D-4 Pre-Upgrade Raw Water Quality Data — 31 Samples (Jan–Dec 2018)
- D-5 Post-Upgrade Treated Water Quality Data — 31 Samples (Jan–Sep 2019)
- D-6 WAWQI Methodology — Parameters, Weights, and Classification (Ayoub, 2017)
- D-7 Statistical Summary — Treated Water (Pre- and Post-Upgrade)
- D-8 Comparative Summary — Welch t-test Results



B	Start of sedimentation basin بداية حوض الترسيب	Residual chlorine الكلور المتبقي	Every 2 h كل ساعتين
C1–C3	Rapid filter units (each) المروقات (كل وحدة)	Residual chlorine · Turbidity الكلور المتبقي، العكارة	Every 2 h كل ساعتين
C1*–C3*	Rapid filters — replicate (microbio) المروقات — مضاعف (ميكروبيولوجي)	Microscopic/biological exam (1 unit) فحص ميكروبيولوجي لعدد 1 (مروقات)	As scheduled حسب الجدول
D1–D4	Filtration units (main) المرشحات (رئيسية)	Residual chlorine · Turbidity الكلور المتبقي، العكارة	Every 2 h كل ساعتين
D1*–D4*	Filtration units — replicate (microbio) المرشحات — مضاعف (ميكروبيولوجي)	Microscopic/biological exam (1 unit) فحص ميكروبيولوجي لعدد 1 (مرشحات)	As scheduled حسب الجدول
E	Underground reservoir — residual Cl الخزان الأرضي — كلور متبقي	Residual chlorine الكلور المتبقي	Every 2 h كل ساعتين
E	Underground reservoir — residual Cl + turbidity الخزان الأرضي — كلور + عكارة	Residual chlorine · Turbidity الكلور المتبقي، العكارة	Every 2 h كل ساعتين
F	Distribution outlet (pump) — full الطرد (طلمبات) — تحليل كامل	pH · Turbidity · EC · TDS · TH · Fe · Mn · Cl · SO <sub>4</sub> · NO <sub>3</sub> · PO <sub>4</sub> · NH <sub>3</sub>	Daily يومي
F*	Distribution outlet — replicate (full + bio) الطرد — مضاعف تحليل كامل + بيولوجي)	Full physicochemical + biological (algae · microbial) تحليل فيزيوكيميائي + بيولوجي (طحالب · فحص ميكروبي)	Daily يومي

Note: Yellow-highlighted rows = full-analysis or composite sampling points. Asterisked points (\*) = replicate samples. All procedures followed APHA Standard Methods (23rd ed.); samples preserved and transported per EN ISO 5667-3; analyses performed at the accredited laboratory of El-Galaa WTP.

## D-2 Chemical Dosing Points

Dosing Point / نقطة الحقن	Description / الوصف
<b>Alum ★</b> نقطة حقن الشببة	Aluminium sulphate solution dosed upstream of the rapid-mixing unit at the coagulation stage. Dosing rate adjusted by jar-test calibration. Pre-upgrade: gravity-fed manual system (>60 mg/L). Post-upgrade: JESCO metering pumps (~35 mg/L optimised). تُحقن محلول كبريتات الألومنيوم قبيل وحدة الخلط السريع في مرحلة التختير. يُضبط معدل الجرعة بناءً على عكارة المياه الخام باستخدام اختبار الجرة.
<b>Primary Cl ★</b> حقن الكلور المبدئي	Pre-chlorination applied upstream of sedimentation/filtration (Point B) to control biological growth. Residual chlorine monitored at C1–C3 every 2 hours. كل C1–C3 للسيطرة على النمو البيولوجي يُراقب الكلور المتبقي عند نقاط (B النقطة) يُطبق الكلور المبدئي قبل مرحلة الترسيب والفلترية ساعتين.
<b>Secondary Cl ★</b> حقن الكلور الثانوي	Post-filtration chlorination at the inlet of the underground reservoir (Point E). Residual free chlorine at distribution outlet F maintained per ES 4081 (0.50–5.00 mg/L). Post-upgrade: JESCO TOPAX DE system. وفق اشتراطات المواصفة F يُحافظ على الكلور الحر المتبقي عند نقطة الطرد (E النقطة) يُطبق الكلور الثانوي عند مدخل الخزان الأرضي المصرية 4081.

**WQI Classification Colour Key (Ayoub, 2017)**

WQI Range	Classification / التصنيف
0 – 25	Excellent / ممتاز
26 – 50	Good / جيد
51 – 75	Poor / ضعيف
76 – 100	Very Poor / ضعيف جداً
> 100	Unsuitable / غير صالح

### D-3 Pre-Upgrade Treated Water Quality Data — 31 Samples (January–December 2018)

Table D-2. WQI per-sample results — Treated Water, Pre-upgrade monitoring period (Jan–Dec 2018) (n = 31). Method: Ayoub (2017) — WAWQIM. Sn per WHO (2011). K = 0.821993; ΣWn = 1.000.

Note: Ca<sup>2+</sup> and Mg<sup>2+</sup> derived from CaH and MgH (mg/L CaCO<sub>3</sub>) using conversion factors 0.4004 and 0.2431 respectively. Mn = 0 (below LOD) for all treated samples. WQI cell colour = classification per Ayoub (2017) scale above.

No	Date	Turb NTU	pH	TH mg/L	TA mg/L	TDS mg/L	Ca <sup>2+</sup> mg/L	Mg <sup>2+</sup> mg/L	Cl <sup>-</sup> mg/L	SO <sub>4</sub> <sup>2-</sup> mg/L	NO <sub>3</sub> <sup>-</sup> mg/L	WQI
Std.	WHO 2011	≤ 1.0	6.5–8.5	≤ 300	≤ 120	≤ 500	≤ 75	≤ 30	≤ 250	≤ 200	≤ 45	< 25
1	01 Jan 2018	0.82	7.29	208	166	361	52.1	19.0	42.0	43.6	2.35	74.37
2	15 Jan 2018	0.60	7.22	216	166	357	48.0	23.3	47.0	46.0	2.2	55.92
3	30 Jan 2018	0.59	7.22	216	162	382	50.5	21.9	39.0	42.0	2.5	54.98
4	10 Feb 2018	0.90	7.21	208	172	329	48.0	21.4	37.0	40.0	2.5	80.31
5	20 Feb 2018	0.50	7.24	192	152	272	48.8	17.0	39.0	43.3	2.6	47.21
6	28 Feb 2018	0.37	7.22	216	164	345	60.1	16.0	42.0	43.5	2.7	36.52
7	10 Mar 2018	0.55	7.25	230	160	293	56.1	21.9	46.0	48.0	2.4	52.07
8	20 Mar 2018	0.54	7.21	216	158	306	58.5	17.0	45.0	49.0	3.6	50.46
9	30 Mar 2018	0.72	7.16	230	164	304	59.3	19.9	44.0	44.2	2.6	65.01
10	10 Apr 2018	0.30	7.19	200	156	305	48.0	19.4	37.0	42.6	2.4	30.50
11	20 Apr 2018	0.40	7.21	226	164	327	58.5	19.4	41.0	40.5	2.5	39.16
12	30 Apr 2018	0.30	7.18	194	154	300	49.6	17.0	28.0	34.6	2.4	30.15
13	10 May 2018	0.69	7.21	216	168	312	48.0	23.3	34.0	30.4	2.1	63.16
14	20 May 2018	0.90	7.23	224	152	330	56.1	20.4	40.0	42.0	2.4	80.44
15	30 May 2018	1.00	7.17	170	140	235	48.0	12.2	25.0	26.4	2.4	86.97
16	10 Jun 2018	0.80	7.25	196	144	300	50.5	17.0	37.0	43.8	2.2	71.95

17	20 Jun 2018	0.65	7.25	200	136	274	52.1	17.0	27.0	40.6	2.0	59.56
18	30 Jun 2018	0.50	7.25	182	160	288	50.5	13.6	27.0	29.0	1.9	47.00
19	10 Jul 2018	0.90	7.21	160	145	248	40.0	14.6	24.0	26.8	4.0	79.36
20	20 Jul 2018	0.45	7.17	194	160	290	53.7	14.6	35.0	39.2	3.0	42.29
21	30 Jul 2018	0.80	7.32	174	160	277	44.0	15.6	40.0	34.6	2.7	72.51
22	10 Aug 2018	0.85	7.22	190	148	285	46.4	18.0	34.0	43.0	2.6	75.80
23	20 Aug 2018	0.60	7.36	214	160	310	56.1	18.0	31.0	36.2	2.1	56.89
24	30 Aug 2018	0.95	7.55	202	160	296	48.8	19.4	34.0	34.2	2.6	87.65
25	10 Sep 2018	1.00	7.54	218	172	328	50.5	22.4	34.0	44.5	2.2	92.04
26	25 Sep 2018	0.83	7.40	225	172	313	54.1	21.9	32.0	46.6	2.9	76.67
27	10 Oct 2018	0.85	7.41	184	148	302	48.0	20.4	32.0	43.0	2.3	77.99
28	25 Oct 2018	1.00	7.41	220	166	333	56.1	19.4	34.0	40.6	2.4	90.49
29	10 Nov 2018	1.00	7.43	210	162	341	52.1	19.4	38.0	44.9	2.4	90.62
30	25 Nov 2018	1.00	7.32	220	162	325	60.1	17.0	39.0	41.6	2.5	89.39
31	04 Dec 2018	1.00	7.43	216	156	314	52.1	20.9	39.0	46.0	2.5	90.73
<b>Mean ± SD</b>	—	<b>0.72±0.23</b>	<b>7.28±0.11</b>	<b>205.4±18.1</b>	<b>158.4±9.2</b>	<b>309.1±31.6</b>	<b>51.75±4.84</b>	<b>18.66±2.87</b>	<b>36.2±6.1</b>	<b>40.3±6.0</b>	<b>2.51±0.42</b>	<b>66.07±19.36</b>
<b>Min</b>	—	<b>0.30</b>	<b>7.16</b>	<b>160</b>	<b>136</b>	<b>235</b>	<b>40.0</b>	<b>12.2</b>	<b>24.0</b>	<b>26.4</b>	<b>1.90</b>	<b>30.15</b>
<b>Max</b>	—	<b>1.00</b>	<b>7.55</b>	<b>230</b>	<b>172</b>	<b>382</b>	<b>60.1</b>	<b>23.3</b>	<b>47.0</b>	<b>49.0</b>	<b>4.00</b>	<b>92.04</b>

Distribution: Excellent 0 (0%) | Good 7 (23%) | Poor 11 (35%) | Very Poor 13 (42%) | Unsuited 0 (0%)

## D-4 Pre-Upgrade Raw Water Quality Data — 31 Samples (January–December 2018)

Table D-3. Physicochemical parameters — Raw Water (El-Kased Canal), Pre-upgrade monitoring period (Jan–Dec 2018) (n = 31). WQI not calculated for raw water. Data presented for source water characterisation only.

No	Date	Turb NTU	pH	TH mg/L	TA mg/L	TDS mg/L	Ca <sup>2+</sup> mg/L	Mg <sup>2+</sup> mg/L	Cl <sup>-</sup> mg/L	SO <sub>4</sub> <sup>2-</sup> mg/L	NO <sub>3</sub> <sup>-</sup> mg/L	Alum mg/L
Std.	—	—	6.5–8.5	≤ 500	—	≤ 1000	≤ 75	≤ 30	≤ 250	≤ 200	≤ 45	—
1	01 Jan 2018	7.50	7.63	162	142	280	40.00	15.10	22.00	24.20	2.20	45.4
2	15 Jan 2018	7.50	7.55	160	154	291	38.40	15.60	22.00	29.00	2.00	44.9
3	30 Jan 2018	6.50	7.52	164	142	280	40.00	15.60	20.00	22.50	2.20	46.2
4	10 Feb 2018	6.50	7.62	170	165	295	44.00	14.60	23.00	23.20	2.00	51.7
5	20 Feb 2018	8.00	7.55	140	138	239	36.00	12.20	22.00	23.60	2.50	56.3
6	28 Feb 2018	9.00	7.55	160	142	227	40.00	14.60	22.00	33.00	2.30	56.3
7	10 Mar 2018	7.55	7.50	152	140	219	40.00	12.60	22.00	28.00	2.00	56.3
8	20 Mar 2018	9.00	7.55	158	142	264	38.40	15.10	22.00	31.00	3.30	60.9
9	30 Mar 2018	10.20	7.52	170	144	227	41.60	16.00	21.00	23.20	2.20	59.8
10	10 Apr 2018	14.00	7.52	150	134	258	39.20	12.60	21.00	25.60	2.20	56.0
11	20 Apr 2018	7.50	7.54	160	142	209	40.00	14.60	21.00	23.50	2.00	46.2
12	30 Apr 2018	10.00	7.52	160	140	204	40.00	14.60	22.00	23.00	2.10	48.8
13	10 May 2018	10.50	7.55	164	146	220	40.00	15.60	22.00	21.20	2.80	47.0
14	20 May 2018	13.00	7.61	152	142	216	39.20	13.10	22.00	29.00	2.00	48.4
15	30 May 2018	13.20	7.52	164	142	210	44.00	13.10	22.00	24.60	2.10	51.7
16	10 Jun 2018	25.00	7.52	134	132	201	37.60	9.70	21.00	27.60	2.00	—
17	20 Jun 2018	12.50	7.56	160	128	186	40.00	14.60	19.00	23.60	1.60	49.0
18	30 Jun 2018	10.50	7.80	144	144	191	36.80	12.60	19.00	22.30	1.80	53.0
19	10 Jul 2018	11.00	7.50	136	140	184	34.40	12.20	18.00	19.30	3.00	53.0

20	20 Jul 2018	13.00	7.44	152	142	184	42.40	11.20	23.00	25.10	2.40	59.0
21	30 Jul 2018	13.00	7.68	160	138	182	40.00	14.60	25.00	24.20	2.10	57.0
22	10 Aug 2018	14.00	7.56	154	130	189	37.60	14.60	22.00	31.00	2.30	55.0
23	20 Aug 2018	10.50	7.77	160	148	197	40.00	14.60	23.00	28.40	2.00	48.0
24	30 Aug 2018	7.50	7.77	160	138	176	40.00	14.60	20.00	26.70	2.30	50.0
25	10 Sep 2018	12.00	7.82	172	148	221	42.40	16.00	23.00	28.00	2.20	—
26	25 Sep 2018	12.00	7.70	168	164	220	36.00	19.00	22.00	26.40	2.40	59.0
27	10 Oct 2018	16.00	7.63	154	138	213	40.00	13.10	21.00	27.00	2.20	56.0
28	25 Oct 2018	12.50	7.69	162	154	240	40.00	15.10	22.00	26.20	2.10	54.0
29	10 Nov 2018	14.00	7.72	160	150	206	40.00	14.60	20.00	24.40	2.20	58.0
30	25 Nov 2018	15.50	7.74	160	142	218	40.80	14.10	22.00	23.50	2.00	53.0
31	04 Dec 2018	16.00	7.75	166	148	229	40.00	16.00	22.00	23.50	2.00	61.0
<b>Mean ± SD</b>	<b>Jan–Dec 2018</b>	<b>11.45±3.79</b>	<b>7.61±0.10</b>	<b>157.7±9.3</b>	<b>143.2±8.2</b>	<b>221.8±33.0</b>	<b>39.68±2.12</b>	<b>14.24±1.74</b>	<b>21.5±1.4</b>	<b>25.5±3.1</b>	<b>2.21±0.33</b>	<b>53.1±4.9</b>

Note: Alum = metered delivery rate (actual). "—" = data not available. Source: El-Galaa WTP laboratory records, Gharbia Water and Wastewater Company (2018).

## D-5 Post-Upgrade Treated Water Quality Data — 31 Samples (January–September 2019)

Table D-4. WQI per-sample results — Treated Water, Post-upgrade monitoring period (Jan–Sep 2019) (n = 31). Method: Ayoub (2017) — WAWQIM. Sn per WHO (2011). K = 0.821993;  $\Sigma W_n = 1.000$ .

Note: Ca<sup>2+</sup> and Mg<sup>2+</sup> derived from CaH and MgH (mg/L CaCO<sub>3</sub>) using factors 0.4004 and 0.2431. Mn = NA (below LOD) in all 2019 samples — excluded from WQI.

No	Date	Turb NTU	pH	TH mg/L	TA mg/L	TDS mg/L	Ca <sup>2+</sup> mg/L	Mg <sup>2+</sup> mg/L	Cl <sup>-</sup> mg/L	SO <sub>4</sub> <sup>2-</sup> mg/L	NO <sub>3</sub> <sup>-</sup> mg/L	WQI
Std.	WHO 2011	≤ 1.0	6.5–8.5	≤ 300	≤ 120	≤ 500	≤ 75	≤ 30	≤ 250	≤ 200	≤ 45	< 25
1	15 Jan 2019	0.10	7.25	180	142	246	48.1	14.6	24.0	28.9	2.2	14.06
2	20 Jan 2019	0.20	7.30	167	140	236	44.6	13.5	25.4	33.0	2.1	22.62
3	25 Jan 2019	0.25	7.22	170	142	239	45.4	13.8	24.0	39.9	2.1	25.97
4	10 Feb 2019	0.20	7.21	162	140	237	43.3	13.1	24.0	34.0	1.9	21.63
5	20 Feb 2019	0.11	7.40	170	148	297	45.4	13.8	26.0	29.0	2.1	16.35
6	28 Feb 2019	0.10	7.30	190	138	304	50.7	15.4	23.0	32.5	1.6	14.67
7	10 Mar 2019	0.15	7.25	194	128	246	51.8	15.7	24.0	30.0	1.8	18.25
8	20 Mar 2019	0.30	7.21	200	152	294	53.4	16.2	27.0	31.6	1.6	30.39
9	31 Mar 2019	0.35	7.23	166	132	253	44.3	13.4	26.0	32.3	1.3	34.15
10	05 Apr 2019	0.30	7.19	180	132	228	48.1	14.6	23.0	29.3	1.8	29.80
11	15 Apr 2019	0.30	7.21	184	134	225	49.1	14.9	24.0	31.6	1.0	30.04
12	25 Apr 2019	0.30	7.18	175	130	237	46.7	14.2	26.0	34.6	1.6	29.64
13	30 Apr 2019	0.20	7.21	180	140	260	48.1	14.6	21.0	30.4	1.7	21.84
14	05 May 2019	0.17	7.23	166	125	234	44.3	13.4	23.0	26.4	1.6	19.30
15	05 May 2019	0.25	7.17	162	138	233	43.3	13.1	25.0	25.6	1.4	25.28
16	15 May 2019	0.30	7.25	168	132	234	44.9	13.6	26.0	25.8	1.4	30.25
17	25 May 2019	0.27	7.25	170	122	211	45.4	13.8	25.0	29.0	2.0	27.78
18	05 Jun 2019	0.12	7.25	210	134	204	56.1	17.0	27.0	26.8	1.7	15.99

19	10 Jun 2019	0.15	7.21	212	138	202	56.6	17.2	24.0	26.8	1.9	18.09
20	20 Jun 2019	0.20	7.17	212	142	208	56.6	17.2	24.0	29.6	2.0	21.83
21	30 Jun 2019	0.30	7.32	210	134	217	56.1	17.0	23.0	30.6	1.9	31.52
22	05 Jul 2019	0.16	7.22	200	135	223	53.4	16.2	25.0	26.7	1.6	18.85
23	15 Jul 2019	0.10	7.30	204	136	220	54.5	16.5	26.0	27.5	1.8	14.81
24	25 Jul 2019	0.10	7.23	200	132	225	53.4	16.2	26.0	30.6	1.5	14.01
25	31 Jul 2019	0.20	7.18	194	138	200	51.8	15.7	28.0	28.7	1.8	21.68
26	05 Aug 2019	0.25	7.20	220	142	204	58.8	17.8	27.0	30.6	1.7	26.34
27	15 Aug 2019	0.23	7.25	190	160	225	50.7	15.4	27.0	30.0	1.6	24.94
28	25 Aug 2019	0.21	7.28	200	150	198	53.4	16.2	24.0	29.0	1.9	23.67
29	01 Sep 2019	0.05	7.32	190	142	200	50.7	15.4	26.0	26.2	1.8	10.75
30	10 Sep 2019	0.17	7.28	200	140	277	53.4	16.2	29.0	24.9	2.0	20.35
31	20 Sep 2019	0.26	7.43	193	132	228	51.5	15.6	27.0	26.3	1.4	29.12
<b>Mean ± SD</b>	—	0.21±0.08	7.25±0.06	187.7±17.1	137.7±7.8	233.7±28.5	50.13±4.56	15.20±1.38	25.1±1.7	29.6±3.2	1.74±0.27	22.71±6.23
<b>Min</b>	—	0.05	7.17	162	122	198	43.3	13.1	21.0	24.9	1.00	10.75
<b>Max</b>	—	0.35	7.43	220	160	304	58.8	17.8	29.0	39.9	2.20	34.15

Distribution: Excellent 19 (61%) | Good 12 (39%) | Poor 0 (0%) | Very Poor 0 (0%) | Unsuitable 0 (0%)

## D-6 WAWQI Methodology — Parameters, Weights, and Classification

The Weighted Arithmetic Water Quality Index (WAWQI) was calculated following Ayoub (2017), applying the framework of Oni & Fasakin (2016) and Phadatare & Gawande (2016). Unit weights ( $W_n$ ) are assigned inversely proportional to the WHO (2011) standard permissible value ( $S_n$ ) of each parameter, ensuring that parameters with stricter standards receive higher relative weight. The proportionality constant  $K$  ensures  $\Sigma W_n = 1$ .

$$\text{WAWQI} = \Sigma [W_n \times q_n] \quad (\text{Eq. 1})$$

$$q_n = [(V_n - V_{id}) / (S_n - V_{id})] \times 100 \quad (\text{Eq. 2})$$

$$W_n = K / S_n \quad (\text{Eq. 3})$$

$$K = 1 / \Sigma (1/S_n) = 0.821993 \quad (\text{Eq. 4})$$

Where:  $V_n$  = measured value;  $V_{id}$  = ideal value (0 for all except pH,  $V_{id} = 7.0$ );  $S_n$  = WHO (2011) permissible standard.

Table D-5. WAWQI parameters, standard permissible values ( $S_n$ ), ideal values ( $V_{id}$ ), unit weights ( $W_n = K/S_n$ ), and weight multipliers ( $W_n \times 1000$ ).  $K = 1/\Sigma(1/S_n) = 0.821993$ ;  $\Sigma W_n = 1.000$ . Source: Ayoub (2017); WHO (2011).

Parameter	$S_n$ (WHO 2011)	$V_{id}$	$K$	$W_n = K/S_n$	$W_n \times 1000$
Turbidity (NTU)	1	0	0.821993	0.821993	821.993
pH	8	7.0	0.821993	0.102749	102.749
Total Hardness (mg/L $\text{CaCO}_3$ )	300	0	0.821993	0.002740	2.740
Total Alkalinity (mg/L)	120	0	0.821993	0.006850	6.850
TDS (mg/L)	500	0	0.821993	0.001644	1.644
$\text{Ca}^{2+}$ (mg/L)	75	0	0.821993	0.010960	10.960
$\text{Mg}^{2+}$ (mg/L)	30	0	0.821993	0.027400	27.400
$\text{Cl}^-$ (mg/L)	250	0	0.821993	0.003288	3.288
$\text{SO}_4^{2-}$ (mg/L)	200	0	0.821993	0.004110	4.110
$\text{NO}_3^-$ (mg/L)	45	0	0.821993	0.018267	18.267
$\Sigma(1/S_n) = 1.216556$   $K = 0.821993$   $\Sigma W_n = 1.000000$					

## D-7 Statistical Summary — Treated Water (Pre- and Post-Upgrade)

Table D-6. Descriptive statistics for treated water physicochemical parameters and WAWQI — Pre-upgrade (2018) and Post-upgrade (2019),  $n = 31$  each period.

Parameter	Unit	Pre 2018 Mean $\pm$ SD	Pre Min	Pre Max	Post 2019 Mean $\pm$ SD	Post Min	Post Max	$\Delta$ (Post-Pre)	% Change
Turbidity	NTU	0.72 $\pm$ 0.23	0.30	1.00	0.21 $\pm$ 0.08	0.05	0.35	-0.52	-71.6%
pH	—	7.28 $\pm$ 0.11	7.16	7.55	7.25 $\pm$ 0.06	7.17	7.43	-0.03	-0.5%
Total Hardness	mg/L	205.4 $\pm$ 18.1	160	230	187.7 $\pm$ 17.1	162	220	-17.7	-8.6%
Total Alkalinity	mg/L	158.4 $\pm$ 9.2	136	172	137.7 $\pm$ 7.8	122	160	-20.6	-13.0%

TDS	mg/L	309.1±31.6	235	382	233.7±28.5	198	304	-75.4	-24.4%
Ca <sup>2+</sup>	mg/L	51.75±4.84	40.0	60.1	50.13±4.56	43.3	58.8	-1.62	-3.1%
Mg <sup>2+</sup>	mg/L	18.66±2.87	12.2	23.3	15.20±1.38	13.1	17.8	-3.47	-18.6%
Cl <sup>-</sup>	mg/L	36.2±6.1	24	47	25.1±1.7	21	29	-11.1	-30.6%
SO <sub>4</sub> <sup>2-</sup>	mg/L	40.3±6.0	26.4	49.0	29.6±3.2	24.9	39.9	-10.7	-26.6%
NO <sub>3</sub> <sup>-</sup>	mg/L	2.51±0.42	1.90	4.00	1.74±0.27	1.00	2.20	-0.78	-31.0%
<b>WAWQI</b>	—	<b>66.07±19.36</b>	<b>30.15</b>	<b>92.04</b>	<b>22.71±6.23</b>	<b>10.75</b>	<b>34.15</b>	<b>-43.36</b>	<b>-65.6%</b>

## D-8 Comparative Summary — Welch t-test Results (Pre- vs. Post-Upgrade)

Table D-7. Comparative summary of treated water parameters and WAWQI: pre-upgrade (2018) vs post-upgrade (2019). Welch t-test (two-tailed,  $\alpha = 0.05$ ). IBM SPSS Statistics v26. Wn = unit weight per Ayoub (2017).

Parameter	Unit	Sn (WHO)	Pre 2018 Mean±SD	Post 2019 Mean±SD	$\Delta$	% Change	Wn (×1000)	t-stat	p-value
Turbidity	NTU	1	0.721±0.227	0.205±0.078	-0.516	-71.6%	821.993	11.96	< 0.001
pH	—	8	7.282±0.107	7.248±0.062	-0.033	-0.5%	102.749	1.49	NS
Total Hardness	mg/L	300	205.4±18.1	187.7±17.1	-17.7	-8.6%	2.740	3.96	< 0.01
Total Alkalinity	mg/L	120	158.4±9.2	137.7±7.8	-20.6	-13.0%	6.850	9.51	< 0.001
TDS	mg/L	500	309.1±31.6	233.7±28.5	-75.4	-24.4%	1.644	9.87	< 0.001
Ca <sup>2+</sup>	mg/L	75	51.75±4.84	50.13±4.56	-1.62	-3.1%	10.960	1.36	NS
Mg <sup>2+</sup>	mg/L	30	18.66±2.87	15.20±1.38	-3.47	-18.6%	27.400	6.07	< 0.001
Cl <sup>-</sup>	mg/L	250	36.2±6.1	25.1±1.7	-11.1	-30.6%	3.288	9.77	< 0.001
SO <sub>4</sub> <sup>2-</sup>	mg/L	200	40.3±6.0	29.6±3.2	-10.7	-26.6%	4.110	8.77	< 0.001
NO <sub>3</sub> <sup>-</sup>	mg/L	45	2.51±0.42	1.74±0.27	-0.78	-31.0%	18.267	8.67	< 0.001
<b>WQI</b>	—	<b>&lt; 25</b>	<b>66.07±19.36</b>	<b>22.71±6.23</b>	<b>-43.36</b>	<b>-65.6%</b>	<b>1.000</b>	<b>11.89</b>	<b>&lt; 0.001</b>

NS = not significant ( $p > 0.05$ ). Green p-values = statistically significant improvement ( $p < 0.05$ ). All analyses performed using IBM SPSS Statistics Version 26.0.

## References

- Ayoub, G.M. (2017). A practical guide to water quality assessment for drinking water treatment. Dar Al-Kotob Al-Ilmiyah, Beirut.
- Oni, O., & Fasakin, O. (2016). The use of water quality index methods to determine the potability of surface water and groundwater in the vicinity of a municipal solid waste dumpsite in Nigeria. American Journal of Engineering Research, 5(10), 96–101.
- Phadatare, A.B., & Gawande, P.D. (2016). Water quality index of different water samples in Pune. IJARSET, 3(1), 1386–1389.
- WHO. (2011). Guidelines for drinking-water quality (4th ed.). World Health Organization.
- APHA-AWWA-WEF. (2017). Standard methods for the examination of water and wastewater (23rd ed.). American Public Health Association.
- Gharbia Water and Wastewater Company. (2018/2019). El-Galaa WTP laboratory records. Studies and Development Department, Gharbia Governorate, Egypt.

## APPENDIX E — SUPPLEMENTARY MATERIAL

### Laboratory Equipment, Instruments & Analytical Methods

*El-Galaa Water Treatment Plant — Water Analysis Laboratory*

<b>Manuscript ID</b>	EEET-04501-2026-02
<b>Journal</b>	Ecological Engineering and Environmental Technology (EEET)
<b>Study Title</b>	Impact of modernization on drinking water quality: A case study of the El-Galaa treatment plant in Egypt
<b>Affiliation</b>	Faculty of Engineering, Tanta University, Tanta, Egypt
<b>Prepared by</b>	Gharbia Water and Wastewater Company — General Laboratories Management
<b>Laboratory</b>	El-Galaa Lab (El-Galaa Water Treatment Plant, Tanta)
<b>Document type</b>	Supplementary Figures — Photographic Documentation

### Analytical Equipment Summary

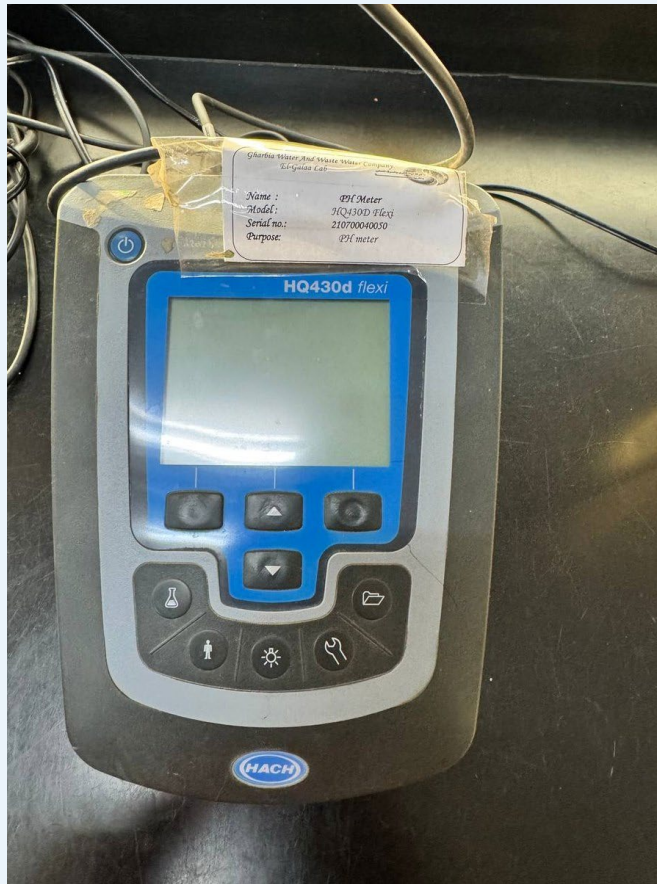
#	Instrument / Equipment	Manufacturer & Model	Serial No.	Next Calibration	Purpose
1	pH / DO / Conductivity Meter	HACH HQ430d Flexi	210700040050	Weekly (electrode)	pH, DO, EC
2	Conductivity/TDS/Temp Meter	ADWA AD8000	H004310007	Weekly (electrode)	EC, TDS, T°C
3	Turbidimeter	HACH TL2300	2019080C0117	Monthly (StablCal)	Turbidity (NTU)
4	UV-Vis Spectrophotometer	HACH DR6000	2362072	31/07/2026	Multi-parameter
5	Residual Chlorine Photometer	DPD Colorimetric	—	Monthly	Free/Total Cl <sub>2</sub>
6	Analytical Balance	Electronic (granite bench)	—	Annually	Reagent weighing
7	Autoclave (Steam Sterilizer)	Witeg WAC-47	D-97877	31/07/2026	Sterilization
8	Drying Oven	Thermo HERATHERM	42459713	31/07/2026	Drying/Gravimetric
9	Jar-Test Flocculator	VELP JLT6	390335	Annually	Coagulant dose opt.

### Analytical Instruments

**Figure 1. HACH HQ430d Flexi Multi-Parameter pH Meter**

Manufacturer: HACH, USA | Model: HQ430d Flexi | S/N: 210700040050

Measures pH, DO, conductivity. Weekly electrode calibration using pH 7 buffer. Deployed at El-Galaa Water Analysis Laboratory.



**Figure 2. ADWA AD8000 Conductivity / TDS / Temperature Meter**

Manufacturer: ADWA, Hungary | Model: AD8000 | S/N: H004310007

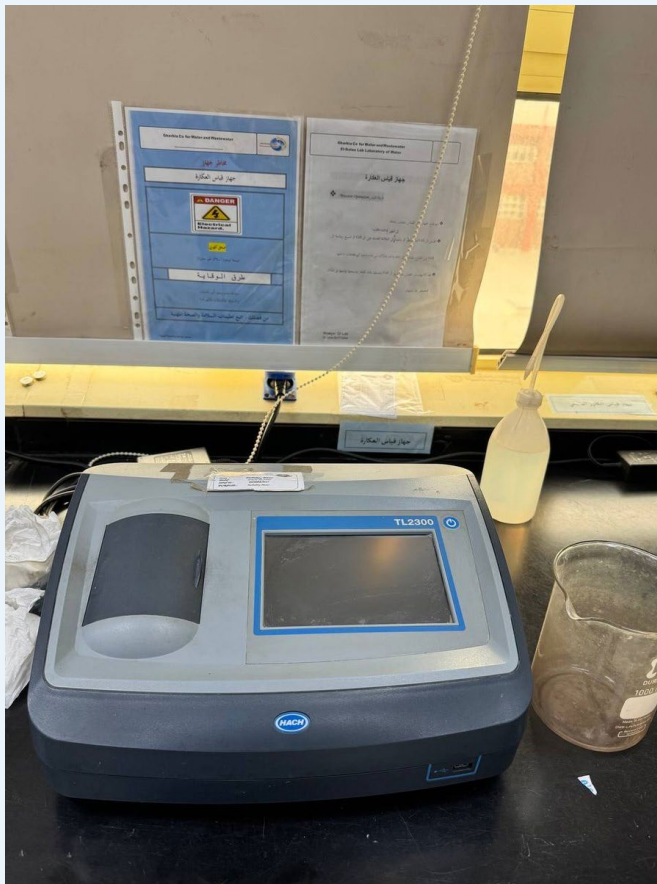
Simultaneous measurement of pH, mV, EC, TDS and temperature. Display reading: 60.4 ppm TDS, 21.7°C at time of photograph.



### Figure 3. HACH TL2300 Laboratory Turbidimeter

Manufacturer: HACH, USA | Model: TL2300 | S/N: 2019080C0117

Measurement range: 0.001–4000 NTU. Calibrated monthly using HACH StablCal primary standards. Used for raw water, settled water and filtered water turbidity.



**Figure 4. HACH DR6000 UV-Vis Spectrophotometer**

*Manufacturer: HACH, USA | Model: DR6000 | S/N: 2362072 | Last Cal.: 31/7/2025 | Next Cal.: 31/7/2026*

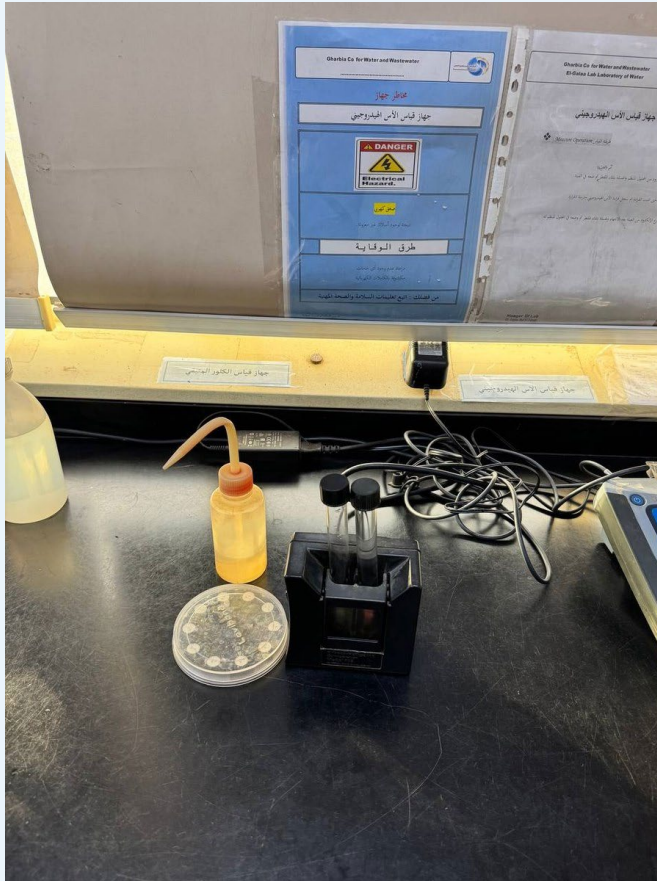
Full spectrum 190–1100 nm. Used for determination of: Fe, Mn, NH<sub>4</sub><sup>+</sup>, NO<sub>2</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup>, SO<sub>4</sub><sup>2-</sup>, Al<sup>3+</sup>, and residual chlorine. Calibration curve R<sup>2</sup> ≥ 0.995.



**Figure 5. Residual Chlorine Colorimetric Photometer**

*Method: DPD (N,N-diethyl-p-phenylenediamine) | DPD1 (free) + DPD3 (total)*

Measures free and total residual chlorine in mg/L. Samples collected every 2 hours at: intake (A), pre-sedimentation (B), filters (C1–C3, D1–D8), ground reservoir (E), and distribution (F).



**Figure 6. Electronic Analytical Balance**

*Installed on vibration-isolated marble/granite bench*

Used for precise weighing of reagent chemicals during standard solution preparation. Anti-vibration platform ensures accuracy to 0.0001 g.



**Figure 7. Witeg Vertical Autoclave (Steam Sterilizer) — General View**

*Manufacturer: Witeg, Germany | Model: Wise Clave WAC-47 | S/N: D-97877*

Steam sterilization at 121°C, 15 psi for 15–20 minutes. Used for sterilization of bacteriological culture media and glassware. Next external calibration: 31/7/2026.



### Figure 8. Witeg Autoclave — Control Panel & Pressure Gauge Detail

*Digital Fuzzy Control System | Pressure gauge: NUOVAFIMA, Italy (EN 837-1) | Range: 0–400 kPa*

Control functions: Set Operation Time, Set Temperature, Safety Locking. Indicators: TIMER, HEAT, ERROR. Pressure gauge reads operating steam pressure in kPa/bar.



**Figure 9. Thermo Scientific HERATHERM Drying Oven**

Manufacturer: Thermo Scientific, USA | Model: HERATHERM | S/N: 42459713 | Last Cal.: 31/7/2025 | Next Cal.: 31/7/2026

Used for drying of filter papers and glassware prior to gravimetric determinations (TSS, TDS by evaporation). Temperature uniformity  $\pm 1^{\circ}\text{C}$ .



## Jar Test & Coagulation

### Figure 10. VELP SCIENTIFICA JLT6 Jar-Test Flocculator (6-Position)

Manufacturer: VELP SCIENTIFICA, Italy | Model: JLT6 | S/N: 390335 | Purpose: Jar Test (Coagulation/Flocculation optimization)

Procedure: (1) 8L turbid water sample collected immediately; (2) Incremental alum doses added to 6 jars; (3) Rapid mix: 150 rpm × 60 s; (4) Slow mix: 80 rpm × 20 s; (5) Settle time per plant design. Used to determine optimum coagulant dose for El-Galaa WTP.



## Chemical Determination Methods

### Figure 11. Determination Bench — Sulfate ( $\text{SO}_4^{2-}$ ) & Manganese (Mn)

$\text{SO}_4$ : Turbidimetric method,  $\lambda = 420 \text{ nm}$  |  $\text{Mn}$ : Persulfate method,  $\lambda = 525 \text{ nm}$

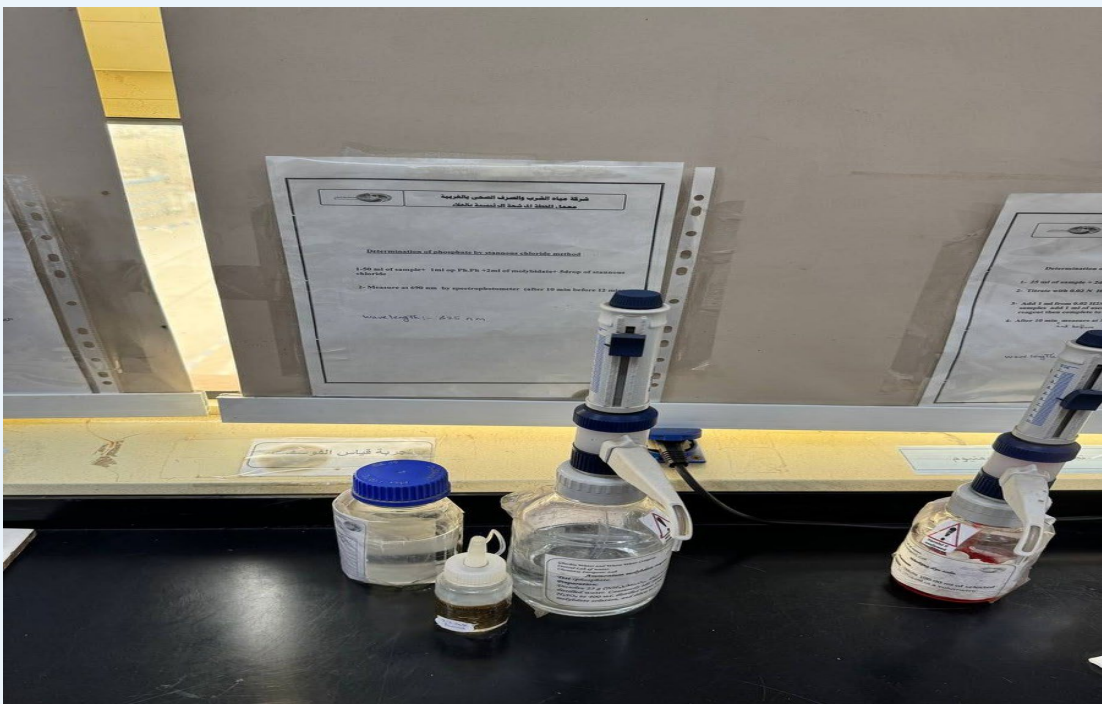
Automatic bottle-top dispensers (Hirschmann) ensure reproducible reagent volumes. Reagents:  $\text{BaCl}_2$  buffer solution ( $\text{SO}_4$ ), potassium persulfate + ammonium persulfate (Mn).



**Figure 12. Determination Bench — Phosphate ( $\text{PO}_4^{3-}$ )**

*Method: Stannous Chloride |  $\lambda = 690 \text{ nm}$  | Measured at DR6000 spectrophotometer*

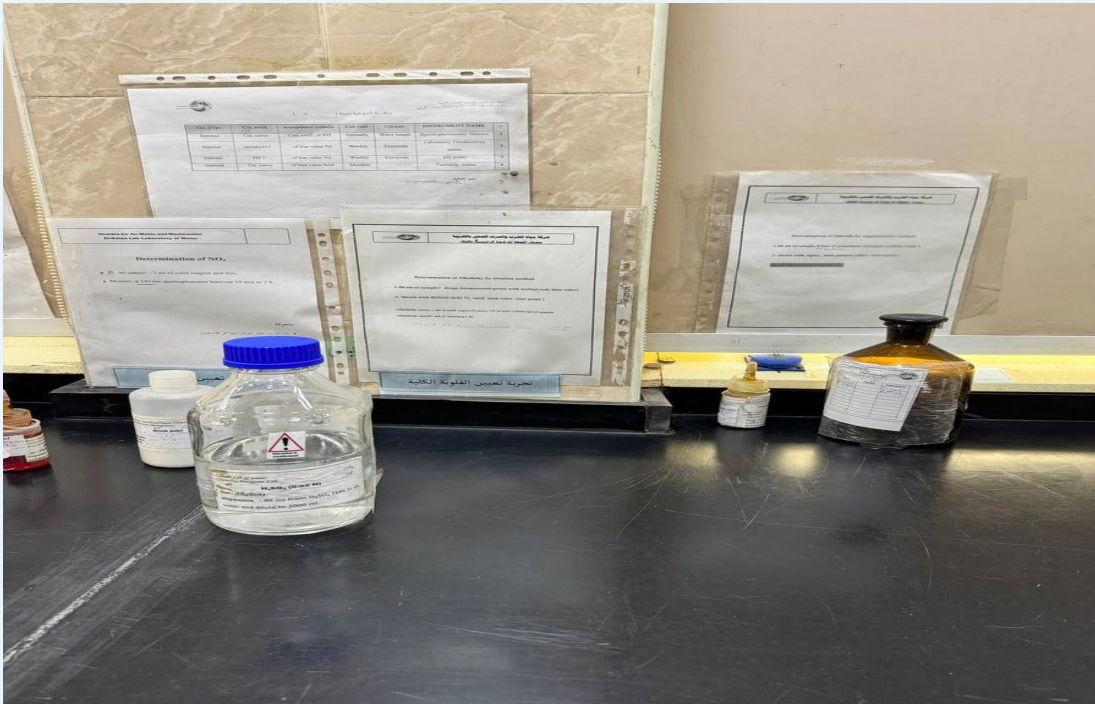
*Protocol: 50 mL sample + 1 mL op.Ph.Ph + 2 mL molybdate + 5 drops  $\text{SnCl}_2$ . Measure 10–12 minutes after reagent addition. Reagents prepared from analytical grade chemicals.*



**Figure 13. Determination Bench — Total Alkalinity & Nitrite (NO<sub>2</sub><sup>-</sup>)**

*Alkalinity: Titration with H<sub>2</sub>SO<sub>4</sub> (0.02 N) | NO<sub>2</sub>: Colorimetric, λ = 543 nm*

Alkalinity: 50 mL sample + bromocresol green/methyl blue indicator, titrate to pink endpoint. NO<sub>2</sub>: 10 mL sample + 2 mL color reagent, measure 10 min–2 h at spectrophotometer. Blank: distilled water with all additives.



**Figure 14. Determination Bench — Ammonium (NH<sub>4</sub><sup>+</sup>)**

*Method: Nessler Reagent | λ = 425 nm*

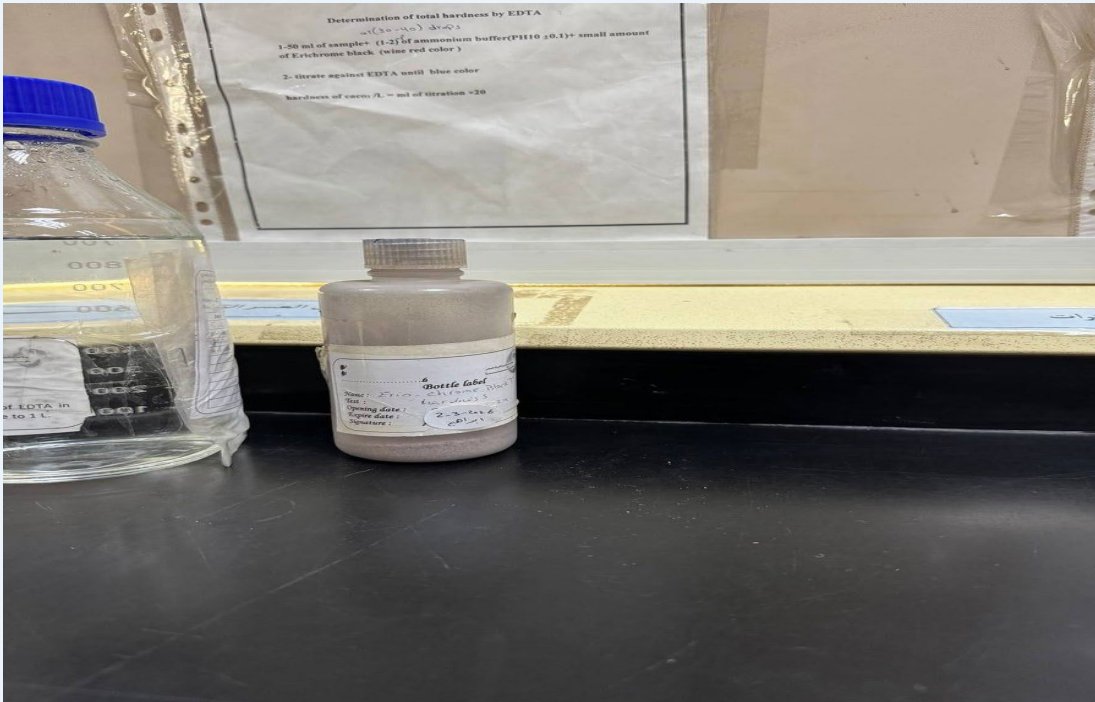
Protocol: 50 mL sample + 2 drops Rochelle salt + 1 mL Nessler reagent. Measure after 10 min (high conc.) or 30 min (low conc.) at spectrophotometer. Blank: distilled water + reagents.



**Figure 16. Total Hardness Determination — Eriochrome Black T Indicator**

*Method: EDTA Complexometric Titration | Buffer: NH<sub>4</sub>Cl/NH<sub>4</sub>OH at pH 10*

*Protocol: 50 mL sample + ammonium buffer (30–40 drops) + small amount Eriochrome Black T, titrate with EDTA to blue endpoint (from wine-red). Total Hardness (mg/L as CaCO<sub>3</sub>) = mL EDTA × 20. Indicator preparation: opened 2/3/2026.*



**Calibration Certificates — شهادات المعايرة**

*The following calibration certificates were issued by the Gharbia Water and Wastewater Company — Laboratory and Quality Sector, confirming traceability to national and international measurement standards.*

**Certificate of Calibration — HACH DR6000 Spectrophotometer (Page 1 of 3)**

*Certificate No: 2025-6-3 | Issued for: □□□□□□ □□□□□□□□ □□□□□□ □□□□ □□□□ | S/N: 2362072 | Date of calibration: June 3, 2025*

شركة مياه الشرب و الصرف الصحي بالقاهرة  
إحدى الشركات التابعة  
للشركة القابضة لمياه الشرب و الصرف الصحي  
إلخام المعامل و الجودة

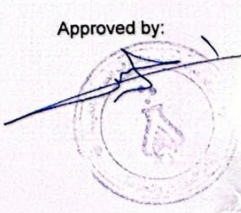
**Certificate of Calibration**

**شهادة معايرة**

Certificate no: 2025-6-3

Issued for:	معمل مياه المرشحة الرئيسية بالجلاء		
Device description:	Spectrophotometer		
Manufacturer:	HACH	Model/ Type:	DR 6000
Serial No:	2362072	Code:	18
Location of calibration:	On-site	Date of calibration:	June 3, 2025
Issue date:	June 4, 2025	Due date:	—

Approved by:



Page 1 of 4

**Wavelength Calibration Results — HACH DR6000 (Page 2 of 3)**

Method: ASTM 275-01 & ASTM 925-02 | Filters: Holmium oxide (HG 39159) & Didymium oxide (DG 39100) | Range: 190–1100 nm | Expanded uncertainty: 2.409%



شركة مياه الشرب و الصرف الصحي بالقاهرة  
 إحدى الشركات التابعة  
 للشركة القومية لمياه الشرب و الصرف الصحي  
 قطاع المعامل و الجودة

**Procedure:**

The method of calibration is based on ASTM 275-01 & ASTM 925-02.

The spectrophotometer mark: **HACH**, model: **DR 6000**, serial number: **2362072**  
 was calibrated for wavelength & photometric accuracy at temperature= 25 c, humidity = 40%. over the wavelength range 190-1100 nm,  
 at spectral band width 1 nm.

**1- Wavelength calibration:**

The wavelength measurements performed by multiple reading of standard Holmium oxide glass filter and standard Didymium oxide glass filter

Filter type	Reference peak (nm)	Wavelength (nm) Reading 1	Wavelength (nm) Reading 2	Wavelength (nm) Reading 3	Wavelength (nm) Reading 4	Average measured absorbance	Maximum Bias
Holmium oxide glass filter No: HG 39159	278.990	278.891	278.979	278.969	278.959	278.949	0.099
	287.420	287.671	287.621	287.721	287.671	287.671	0.301
	333.800	333.882	333.632	333.862	333.902	333.820	0.168
	360.780	360.889	360.839	360.859	360.859	360.862	0.109
	418.730	418.653	418.753	418.853	418.833	418.773	0.123
	445.890	446.110	446.140	446.090	446.160	446.125	0.270
	453.590	453.912	453.932	453.912	453.932	453.922	0.342
	460.160	460.164	460.194	460.224	460.214	460.199	0.064
Didymium oxide glass filter No: DG 39100	472.440	472.817	472.807	472.767	472.787	472.794	0.377
	513.490	513.848	513.927	513.947	513.897	513.905	0.457
	528.890	529.231	529.281	529.201	529.241	529.238	0.391
	573.330	573.672	573.542	573.622	573.562	573.599	0.342
	585.280	585.645	585.425	585.545	585.485	585.525	0.365
	684.470	685.669	684.679	684.569	684.609	684.882	1.199
	740.340	740.383	740.373	740.363	740.343	740.365	0.043

The estimated expanded uncertainty in the wavelength measurements equal (%): **2.409**

**Photometric Calibration Results — HACH DR6000 (Page 3 of 3)**

Filters: Neutral density glass (No: 13436) & K2Cr2O7 60 mg (No: 13898) | Wavelengths: 235–635 nm | All readings within certified absorbance values



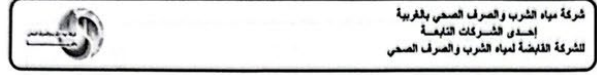
**2- Photometric Calibration:**

The absorbance measurements performed by multiple reading of standard neutral density glass filter and standard potassium dichromate 60 mg filter

Filter No	wavelength (nm)	Certificated filter Absorbance	Absorbance (AU) Reading 1	Absorbance (AU) Reading 2	Absorbance (AU) Reading 3	Absorbance (AU) Reading 4	Average measured absorbance	Maximum Bias
Neutral density glass filter No: 13436	635	0.1450	0.158439125	0.15623858	0.158439125	0.157338853	0.1576	0.013
	590	0.1435	0.15513831	0.15293777	0.156238581	0.154038038	0.1546	0.013
	546	0.1357	0.14853668	0.14853668	0.146336136	0.147436408	0.1477	0.013
	465	0.1356	0.146336136	0.14743641	0.145235864	0.146336136	0.1463	0.012
K2Cr2O7 60 mg filter No: 13898	440	0.1497	0.16173994	0.16063967	0.16173994	0.159539397	0.1609	0.012
	350	0.6415	0.709675247	0.70692457	0.706924567	0.706374431	0.7075	0.068
	313	0.2911	0.309286375	0.32028909	0.320289092	0.320289092	0.3175	0.029
	257	0.8649	0.956136107	0.95272527	0.951624993	0.947333934	0.9520	0.091
235	0.7428	0.818602145	0.81728182	0.817281819	0.824983721	0.8195	0.082	

**Certificate of Calibration — Witeg Autoclave WITEG/WAS-47 (Page 1 of 2)**

Certificate No: 25/07/102 | Issued for: □□□□□□ □□□□□□□□ □□□□□□ □□□□ | S/N: D-97877 | Date of calibration: 29/07/2025 | Issue Date: 31/07/2025



Certificate of Calibration

شهادة معايرة

Certificate No: 25/07/102

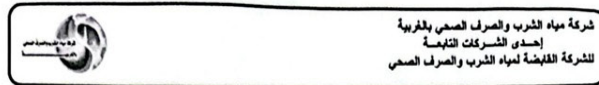
Issued for :	معمل المحطة المرشحة الرئيسية بطنطا		
Description:	Autoclave		
Manufacturer:	-----	Model/ Type:	WITEG/WAS-47
Serial No:	D-97877	Code No:	-----
Date of calibration:	29/07/2025	Issue Date:	31/07/2025

Approved by:



**Autoclave Calibration Results — Temperature Repeatability (Page 2 of 2)**

Method: Direct Calibration per Euramet eg-08/ver.3.0 | Reference: Thermocouple Calibrator (S/N: 150315077, Model: 4233) | Conditions: 22.4±0.5°C, RH: 54±2% | Uncertainty: K=2 (95% confidence)



**Calibration Method**

Direct Calibration method according to standard Euramet eg-08/ver.3.0

**Standard**

Reference Device	Serial No.	Model
Thermocouple Calibrator	150315077	4233

This calibration certificate documents the tractability to the national standards or accredited calibration laboratory according to ITS-90, which realize the units of measurement (SI Units)

**Ambient Condition**

Temperature (°C)	Relative Humidity (RH%)
22.4 ± 0.5	54 ± 2

**Uncertainty**

The expand uncertainty is stated as the standard combined uncertainty of measurement multiplied by the coverage factor K=2, and represents the 95% level of Confidence

**Calibration results**

**Repeatability Test**

Reference Value (°C)	Measured (°C)	Error(°C)	Uncertainty(±°C)
120.5	121	0.5	0.4
123.8	124	0.2	0.2
128.6	130	1.4	0.8

Calibrated by:

Reviewed by

# SUPPLEMENTARY EVIDENCE

## Clarification Units — Physical Dimensions, HRT & Field Evidence

El-Galaa Water Treatment Plant, Tanta | Manuscript EEET-04501-2026-02

Response to Reviewer Comment 15 [supplement what has been said with real evidence]

### 1. Revised Manuscript Paragraph

The following paragraph replaces the original text, incorporating the dimensional and hydraulic data requested by the reviewer:

#### Clarification units

The plant was equipped with seven circular clari-flocculators, each with an outer diameter of **20.00 m**, a side water depth (SWD) of **4.90 m**, and a nominal treatment capacity of approximately 40 L s<sup>-1</sup>, corresponding to a theoretical hydraulic retention time (HRT) of approximately **10.2 hours** per unit and a theoretical total clarification capacity of approximately 280 L s<sup>-1</sup>. In practice, the effective plant throughput was constrained by hydraulic limitations in downstream treatment units.

Operational challenges were observed in the sludge management system. Sludge removal was performed irregularly, resulting in excessive sludge accumulation within the clarifiers. This accumulation reduced the effective basin volume and shortened the hydraulic retention time (HRT), thereby decreasing clarification efficiency and limiting the overall hydraulic capacity of the plant.

### 2. Physical Dimensions — Source Data

All dimensions extracted from original structural drawings (Plan View + Cross-Section A-A, A0 sheet) and verified against the contractor scope of works document.

Parameter	Value	Source
Outer diameter	<b>20.00 m</b>	Structural drawings
Net internal diameter	<b>19.50 m</b>	Calculated (wall = 0.25 m)
Plan area (net)	298.6 m <sup>2</sup>	$\pi/4 \times 19.50^2$
Total structural depth	<b>5.15 m</b>	Cross-section A-A (+8.08 to +13.23)
Side water depth (SWD)	<b>4.90 m</b>	5.15 – 0.25 m freeboard
Number of units	<b>7 units</b>	Contractor scope of works

### 3. Hydraulic Calculations — HRT and SOR

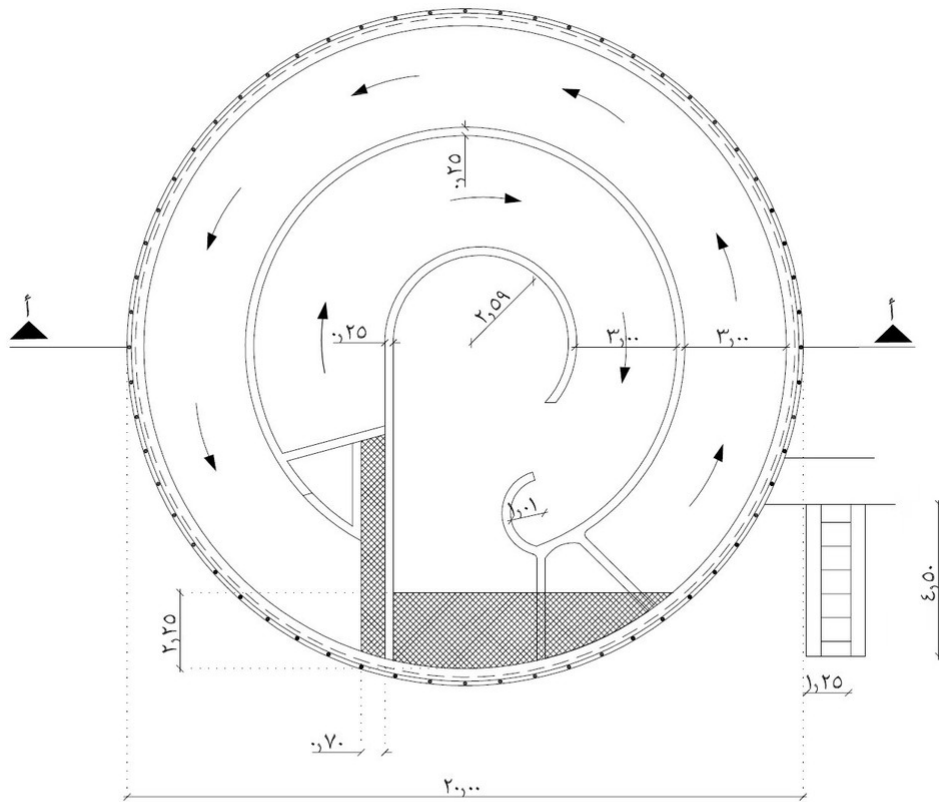
Design unit flow: 40 L s<sup>-1</sup> per basin = 3,456 m<sup>3</sup> day<sup>-1</sup>. Formulae:  $A = \pi/4 \times D^2$  |  $V = A \times SWD$  |  $HRT = V/Q$   
|  $SOR = Q/A$

Parameter	Value	Formula
Design flow rate	40 L s <sup>-1</sup>	Per unit — contractor basis
Unit basin volume	1,463 m <sup>3</sup>	298.6 × 4.90
Theoretical HRT	10.2 hours	V/Q = 1463/0.040
SOR	11.57 m <sup>3</sup> m <sup>-2</sup> day <sup>-1</sup>	3456 / 298.6

## 4. Engineering Drawings

Original structural drawings from Al-Galaa WTP archive confirming basin geometry and hydraulic levels.

Figure D1 | Structural Plan View — Circular Clarifier (Pre-Upgrade)

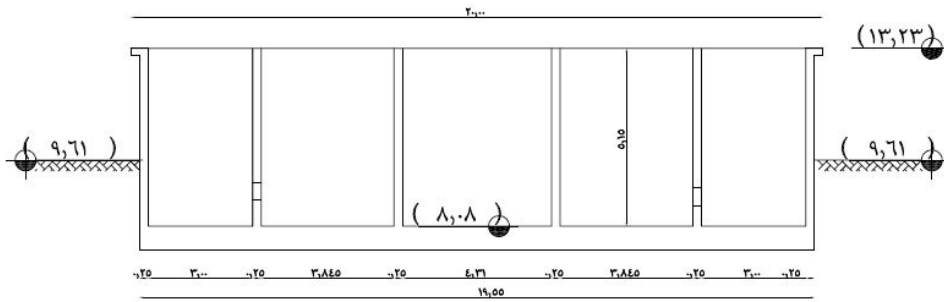


مسقط أفقى للمروق قبل التطوير

**Field evidence:** Plan view (مسقط أفقى للمروق قبل التطوير) showing the circular basin with outer diameter 20.00 m, central inlet zone, internal spiral flow path, and peripheral overflow channel. Confirms radial-flow configuration and 0.25 m wall thickness.

**Keywords:** plan view, D=20.00 m, central inlet, peripheral weir, radial flow, Al-Jalaa WTP

Figure D2 | Cross-Section A-A — Vertical Profile (Pre-Upgrade)



قطاع رأسي (أ-أ)  
 ١٠٠/١

**Field evidence:** Vertical cross-section (قطاع رأسي أ-أ, Scale 1:100) showing total structural depth 5.15 m (levels +8.08 to +13.23 m), inlet pipe level at +9.61 m, and internal partition walls dividing the basin cross-section. SWD = 4.90 m after deducting 0.25 m freeboard. Internal width dimension chain confirms net internal diameter of 19.55 m  $\approx$  19.50 m.

**Keywords:** cross-section, SWD=4.90 m, total depth=5.15 m, level +8.08, level +13.23, freeboard

## 5. Field Photographs — Pre-Upgrade Conditions

Photographs taken during site inspection visits to El-Galaa WTP prior to the 2019 rehabilitation, documenting the existing basin configuration and sludge management practices.

**Figure P1 | Pre-Upgrade Circular Clarifiers — In Operation**



**Field evidence:** Aerial view of the pre-upgrade circular clarifiers at Al-Jalaa WTP showing multiple shallow open basins in continuous operation. The absence of mechanical scraper bridges or rotating sludge collection arms is clearly visible — confirming that the basins relied entirely on manual desludging. Historical buildings in the background date the original infrastructure to the early 20th century. This image provides direct visual confirmation of the seven-unit, manually operated clarification system described in the manuscript.

**Keywords:** *pre-upgrade, circular clarifiers, no mechanical scraper, manual operation, Al-Jalaa WTP, Tanta*

**Figure P2 | Dried Sludge Accumulation Outside Basin Wall**



**Field evidence:** Ground-level photograph showing the exterior face of a circular clarifier wall with a thick layer of dried, cracked sludge deposited on the surrounding ground. The polygonaally cracked mud surface and spontaneous weed growth indicate prolonged sludge stockpiling over multiple desludging cycles. This evidence demonstrates that sludge extracted from the basins had no formal dewatering or disposal route, and was simply spread adjacent to the structure — a direct consequence of the absence of a mechanical sludge management system. This directly supports the manuscript's statement that sludge removal was performed irregularly.

**Keywords:** *sludge accumulation, irregular desludging, no sludge disposal facility, cracked mud, pre-upgrade*

**Figure P3 | Site Conditions — Pre-Upgrade Infrastructure**



**Field evidence:** Photograph of the plant building complex prior to rehabilitation works, showing the general state of the infrastructure. Debris, construction spoil, and accumulated sediment visible on the ground adjacent to the main structure indicate that the site had not undergone systematic maintenance in the period leading up to the 2019 upgrade. This image contextualises the overall condition of the plant at the time of assessment and supports the documented need for comprehensive rehabilitation.

**Keywords:** *pre-upgrade site, infrastructure condition, maintenance deficit, pre-rehabilitation*

**Figure P4 | Manual Sludge Removal Using Excavator — Large-Scale Accumulation**



**Field evidence:** Field photograph documenting the manual desludging operation at one of the pre-upgrade circular clarifiers. A tracked hydraulic excavator is actively extracting and spreading accumulated sludge directly outside the basin perimeter. The thick black sludge layer spread across a wide area of the surrounding ground — extending several metres from the basin wall — is striking evidence of the volume and density of material that had built up before removal. Workers visible in the background provide scale. The sheer quantity of extracted sludge confirms that desludging cycles were infrequent and that substantial volumes of settled solids had accumulated within the basin, directly reducing the effective hydraulic volume and shortening the actual HRT below the theoretical 10.2-hour design value. The absence of any controlled sludge dewatering or disposal facility is apparent — material was simply excavated and deposited adjacent to the structure, consistent with the irregular sludge management practice described in the manuscript.

**Keywords:** *manual desludging, excavator, large-scale sludge accumulation, HRT reduction, pre-upgrade, intermittent operation*

# APPENDIX G

## In-Line Rapid Mixing System

Supplementary Field Evidence — Pre-Upgrade Coagulation Configuration

<b>Plant</b>	El-Galaa Water Treatment Plant, Tanta, Gharbia, Egypt
<b>Manuscript ID</b>	EEET-04501-2026-02
<b>Reviewer Comment</b>	C14 — In-line rapid mixing system
<b>Evidence Sources</b>	Field photography + operator testimony + operational records (2018)
<b>Data Period</b>	1 January 2018 – 4 December 2018 (31 measurement points)
<b>Appendix Version</b>	v5 (final — corrected seasonal statistics, explicit rapid-mixing equipment statement)

### Scope of this Appendix

This appendix provides quantitative and photographic supplementary evidence in response to Reviewer Comment C14. It documents: (1) the technical description of the pre-upgrade gravity-fed alum dosing system; (2) complete operational dosage records for 2018 (n = 31 measurement points); (3) field photographs from the March 2026 site visit; and (4) the revised manuscript text and full reviewer response.

## G.1 Pre-Upgrade Dosing System — Technical Description

Prior to the 2019 upgrade, coagulation at El-Galaa WTP was achieved through in-line alum dosing into the raw water pipeline upstream of the clarification units. Liquid aluminium sulphate ( $\text{Al}_2(\text{SO}_4)_3$ ), supplied by the Egyptian Alum Company (ASCE), was stored in elevated galvanised steel tanks. The solution was prepared at a calculated concentration in a purpose-built dilution basin and delivered into the raw water main entirely by gravity feed. The flow rate drawn from the storage tanks was regulated by a float-type flowmeter (rotameter) on the draw-off line. No mechanical dosing pumps or automated control systems were installed; all dosage adjustments were performed manually by operators based on visual turbidity assessment.

Since rapid mixing was achieved solely through the hydraulic turbulence of the flowing raw water, the system had no independent means of controlling mixing intensity (G-value / Camp number) or hydraulic residence time (HRT). As a consequence, coagulation efficiency was directly coupled to pipeline flow conditions and was highly sensitive to fluctuations in raw water turbidity and flow rate.

### G.1.1 System Component Summary

Parameter	Description / Value
Chemical reagent	Liquid Aluminium Sulphate — $\text{Al}_2(\text{SO}_4)_3$
Supplier	Egyptian Alum Company (ASCE)
Storage vessels	Elevated galvanised steel tanks (cylindrical)
Concentration control	Purpose-built concrete dilution basin
Dosing mechanism	Gravity-fed — no mechanical dosing pumps
Flow monitoring	Float-type flowmeter (rotameter) on draw-off line
Dose adjustment	Manual — operator reads rotameter & adjusts valve
Rapid mixing energy	Pipeline hydraulic turbulence only (in-line)
G-value / Camp no.	Uncontrolled — function of pipeline flow velocity
HRT control	None — contact time = f(pipe length & flow rate)
Applied dose range	42 – 55 mg/L (annual mean: 46.7 mg/L, 2018)
Actual dose range	44.9 – 63.3 mg/L (annual mean: 53.4 mg/L, 2018)
Mean overdosing	+ 6.7 mg/L (+14.3% above applied target)

## G.2 Operational Alum Dosage Records — 2018 (n = 31)

Table G.1 presents the complete set of alum dosage records for the pre-upgrade period (2018), extracted from the plant operational database (Raw Water Quality Register, El-Galaa WTP). Applied dose refers to the target dosage set by the operator; actual dose represents the measured quantity delivered to the raw water main, back-calculated from rotameter readings and tank draw-down measurements.

**Table G.1. Pre-upgrade operational alum dosage records, El-Galaa WTP (2018).**

#	Date	Applied (mg/L)	Actual (mg/L)	Δ (mg/L)	Overdose (%)	Season	Note
1	01 Jan 2018	42	45.36	3.36	8.0%	Winter	
2	15 Jan 2018	42	44.94	2.94	7.0%	Winter	
3	30 Jan 2018	42	46.20	4.20	10.0%	Winter	
4	10 Feb 2018	45	51.75	6.75	15.0%	Winter	
5	20 Feb 2018	49	56.35	7.35	15.0%	Winter	
6	28 Feb 2018	49	56.35	7.35	15.0%	Winter	
7	10 Mar 2018	49	56.35	7.35	15.0%	Spring	
8	20 Mar 2018	53	60.95	7.95	15.0%	Spring	High turbidity
9	30 Mar 2018	52	59.80	7.80	15.0%	Spring	High turbidity
10	10 Apr 2018	50	56.00	6.00	12.0%	Spring	High turbidity
11	20 Apr 2018	44	46.20	2.20	5.0%	Spring	
12	30 Apr 2018	44	48.84	4.84	11.0%	Spring	
13	10 May 2018	42	47.04	5.04	12.0%	Spring	
14	20 May 2018	44	48.40	4.40	10.0%	Spring	
15	30 May 2018	45	51.75	6.75	15.0%	Spring	
16	10 Jun 2018	55	63.25	8.25	15.0%	Summer	Peak dose ↑
17	20 Jun 2018	45	49.00	4.00	8.9%	Summer	
18	30 Jun 2018	48	53.00	5.00	10.4%	Summer	
19	10 Jul 2018	49	53.00	4.00	8.2%	Summer	
20	20 Jul 2018	51	59.00	8.00	15.7%	Summer	High turbidity

21	30 Jul 2018	47	57.00	10.00	21.3%	Summer	
22	10 Aug 2018	49	55.00	6.00	12.2%	Summer	
23	20 Aug 2018	43	48.00	5.00	11.6%	Summer	
24	30 Aug 2018	43	50.00	7.00	16.3%	Summer	
25	10 Sep 2018	45	51.75	6.75	15.0%	Autumn	
26	25 Sep 2018	51	59.00	8.00	15.7%	Autumn	High turbidity
27	10 Oct 2018	46	56.00	10.00	21.7%	Autumn	
28	25 Oct 2018	44	54.00	10.00	22.7%	Autumn	
29	10 Nov 2018	47	58.00	11.00	23.4%	Autumn	
30	25 Nov 2018	45	53.00	8.00	17.8%	Autumn	
31	04 Dec 2018	48	61.00	13.00	27.1%	Winter	
<b>Annual Statistics (n=31)</b>		<b>42–55 Mean: 46.7</b>	<b>44.9–63.3 Mean: 53.4</b>	<b>2.9–13.0 Mean: 6.7</b>	<b>7.0–27.1% Mean: 14.3%</b>	All seasons	<b>Systematic overdosing</b>

### Key Statistical Findings

- ▶ Applied dose range: 42 – 55 mg/L | Annual mean: 46.7 mg/L | Median: 46.0 mg/L
- ▶ Actual dose range: 44.9 – 63.3 mg/L | Annual mean: 53.4 mg/L | Median: 53.0 mg/L
- ▶ Mean overdose: +6.7 mg/L (+14.3% above applied target) across all 31 records
- ▶ Maximum overdose: +13.0 mg/L (+27.1%) on 04 December 2018
- ▶ Seasonal peak: Applied 55 mg/L / Actual 63.3 mg/L on 10 June 2018 (summer flood)
- ▶ March (peak flood month): mean applied 51.3 mg/L / mean actual 59.0 mg/L — highest of any period
- ▶ All 31 records show Actual > Applied — confirming systematic gravity-fed overdosing

### G.3 Photographic Evidence — Field Visit, March 2026

The following photographs were taken during a structured field inspection of El-Galaa WTP in March 2026. They document the pre-upgrade gravity-fed dosing infrastructure and provide direct visual evidence of the excess sludge production associated with uncontrolled in-line coagulation.



**Figure G.1**

*Elevated galvanised steel alum storage tank (left) and cylindrical dilution basin (right). The elevation of the storage tank provides the hydraulic head that drives the gravity-fed dosing system. No dosing pumps or automated control equipment are present.*



**Figure G.2**

*Spherical fibre-reinforced dilution vessel and associated pipework. This vessel served as the concentration-adjustment basin. The absence of flow instrumentation on the main outlet confirms the reliance on manual operator control described in the manuscript.*



**Figure G.3**

*Liquid alum storage tank (ASCE — Egyptian Alum Company) with graduated level gauge. Stock volume estimation via the level gauge, combined with the rotameter reading, was the only available means of inferring dosage. No inline mass-flow measurement was available.*



**Figure G.4 — KEY EVIDENCE**

*Substantial alum sludge accumulation at the base and drainage apron of the alum storage tank. The orange-brown granular precipitate is consistent with aluminium hydroxide generated by coagulant overdosing under insufficient mixing energy. This directly corroborates the quantitative overdosing pattern documented in Table G.1 (mean overdose +14.3%; peak +27.1%).*

## **G.4 Sludge Accumulation — Field Observations (Fig. G.4)**

The sludge accumulation visible in Figure G.4 constitutes direct physical evidence of the operational failure mode described in the manuscript. Field observations are summarised below.

Observation	Detail
<b>Sludge texture</b>	Granular, friable; orange-brown coloration
<b>Location</b>	Base and full perimeter of drainage apron, alum storage tank
<b>Estimated coverage</b>	Extends along entire tank perimeter (~full apron width)
<b>Quantitative link</b>	Consistent with mean overdose of +6.7 mg/L (+14.3%) — Table G.1
<b>Root cause (inferred)</b>	Coagulant overdosing under insufficient hydraulic mixing energy
<b>Implication</b>	Confirms excess Al(OH) <sub>3</sub> precipitation and poor floc formation

## G.5 Final Revised Manuscript Paragraph (Ready for Insertion)

The following paragraph is the final revised text for insertion into the manuscript in response to Editor Comment C14. It incorporates: the dosing method, equipment type, operational dosage range (from Table G.1), and real observational/quantitative evidence as requested by the Editor.

— Insert into Section 2.3 (Pre-Upgrade Treatment Configuration) —

Coagulation was achieved through in-line alum dosing into the raw water pipeline upstream of the clarification units. Prior to the 2019 upgrade, liquid aluminium sulphate ( $\text{Al}_2(\text{SO}_4)_3$ ), supplied by the Egyptian Alum Company (ASCE), was stored in elevated galvanised steel tanks and delivered into the raw water main by gravity feed, without mechanical dosing pumps, automated control systems, or dedicated rapid-mixing equipment. A purpose-built dilution basin allowed operators to prepare the alum solution at a pre-calculated concentration. The draw-off flow rate was monitored by a float-type flowmeter (rotameter) installed on the storage tank outlet line; all dosage adjustments were performed manually by operators based on visual turbidity assessment of the raw water intake.

Operational records for 2018 ( $n = 31$  measurement points) confirm that the applied dose ranged from 42 to 55 mg/L (annual mean: 46.7 mg/L), with the highest values recorded during the spring flood season along the El-Qassid Canal (March mean: 51.3 mg/L applied; 59.0 mg/L actual). Critically, the actual measured dose exceeded the applied target in all 31 records, with a mean overdose of +6.7 mg/L (+14.3%) and a maximum of +13.0 mg/L (+27.1%). This systematic overdosing is a characteristic failure mode of manual gravity-fed systems, in which operators compensate for inadequate mixing energy by increasing the coagulant dose rather than by enhancing mixing intensity.

Since rapid mixing was achieved solely through the hydraulic turbulence of the flowing raw water, the system lacked any independent means of regulating mixing intensity (G-value / Camp number) or hydraulic residence time (HRT). Under elevated turbidity conditions, insufficient turbulent energy resulted in incomplete charge neutralisation and poor microfloc aggregation, which in turn required further dose escalation — culminating in excess aluminium hydroxide sludge generation. Field observations conducted during this study (March 2026) confirmed significant sludge accumulation around the base of the alum storage tanks (Fig. G.4, Appendix G), providing direct visual corroboration of the quantitative overdosing pattern documented in the operational records. This finding is consistent with published evidence indicating that uncontrolled gravity-fed coagulation systems are particularly susceptible to coagulant overdosing and elevated sludge yields under variable raw water quality (Crittenden et al., 2012; MWH, 2012).

## G.6 Response to Reviewer — Comment C14

### Reviewer Comment C14:

*"While inline alum injection in the raw water pipeline achieved coagulation, it eliminated the need for special mechanical mixing equipment. However, the absence of such mixers hampered proper regulation of mixing intensity and duration, especially under highly turbid conditions. This resulted in insufficient aggregate formation and increased sludge production."*

**Authors' Response:**

We thank the reviewer for this important observation. The manuscript has been substantially revised to provide a technically accurate, evidence-supported description of the pre-upgrade coagulation system, incorporating all three elements requested by the Editor: dosing method, equipment type, and operational dosage range.

Field investigations and interviews with long-serving plant operators confirmed that the pre-2019 dosing system was gravity-fed, not pump-driven. Liquid alum ( $\text{Al}_2(\text{SO}_4)_3$ , Egyptian Alum Company — ASCE) was stored in elevated galvanised steel tanks, prepared in a dilution basin, and delivered to the raw water main by gravity. A float-type flowmeter (rotameter) on the draw-off line was the only instrumentation available; no automated dosing control existed.

Operational records for 2018 ( $n = 31$ ) quantify the consequences of this configuration: the applied dose ranged from 42–55 mg/L (mean: 46.7 mg/L), while the actual measured dose consistently exceeded the target — by a mean of +6.7 mg/L (+14.3%) and up to +13.0 mg/L (+27.1%) — confirming systematic overdosing across all seasons. Peak doses coincided with high-turbidity flood periods, exactly as described by the reviewer.

Since rapid mixing depended entirely on pipeline hydraulic turbulence, the system could not independently regulate G-value or HRT. This precluded adequate mixing under variable flow conditions and compelled operators to compensate via dose escalation, generating excess  $\text{Al}(\text{OH})_3$  sludge. Field photography from March 2026 (Fig. G.4, Appendix G) provides direct visual confirmation of substantial sludge accumulation, linking the quantitative overdosing record to the physical outcome described by the reviewer. Supporting literature (Crittenden et al., 2012; MWH, 2012) corroborates these findings.

The manuscript has been revised accordingly (Section 2.3). The complete operational dataset and photographic evidence are provided in Appendix G.

## G.7 References

Crittenden, J.C., Trussell, R.R., Hand, D.W., Howe, K.J. and Tchobanoglous, G. (2012) *MWH's Water Treatment: Principles and Design*, 3rd edn. John Wiley & Sons, Hoboken, NJ.

MWH (2012) *Water Treatment: Principles and Design* — see Crittenden et al. (2012).

Gharbia Water and Wastewater Company (2026) *Field Inspection Report* — El-Galaa WTP, Tanta. Internal technical documentation, March 2026.

El-Galaa WTP Operations Department (2018) *Raw Water Quality Register — Alum Dosage Records*. Internal operational database, Gharbia Water and Wastewater Company, Tanta.

El-Galaa WTP Operators (2026) Oral testimony, structured field interview, March 2026. Recorded in El-Galaa WTP Site Visit Field Survey Protocol.

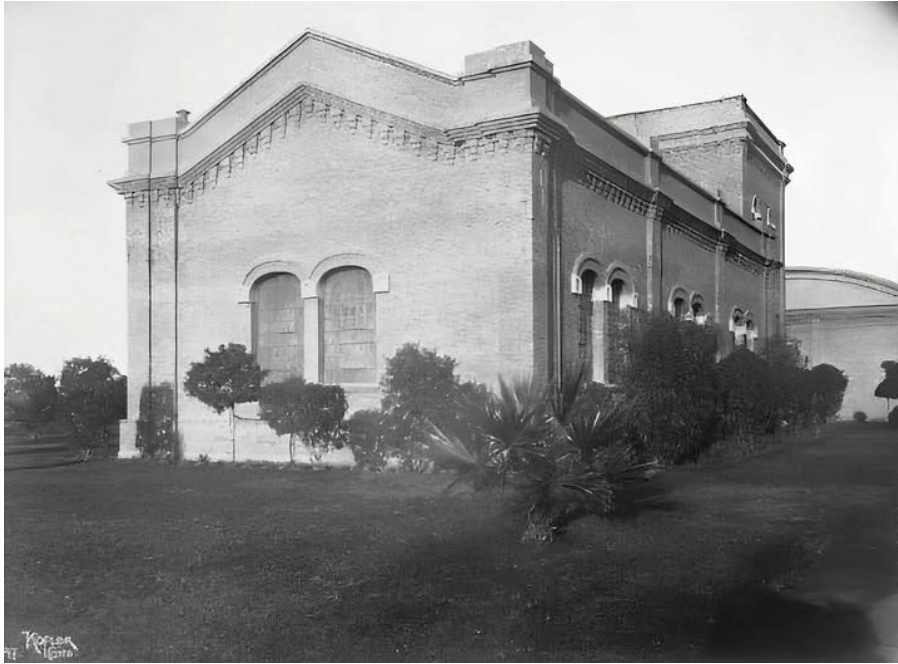
## Appendix H

### *Historical Background and Archival Documentation: El-Galaa Water Treatment Plant*

#### H.1 Establishment and Early Infrastructure

The El-Galaa Water Treatment Plant (WTP) in Tanta was originally commissioned in **1924** under the municipal water authority of Tanta City. Construction was carried out by **J. Garozzo & Sons**, a contracting company active in Egypt during the early twentieth century. The original infrastructure included a pump station and a filter building, both constructed in the neo-classical brick architectural style characteristic of Egyptian public works of that period, featuring arched windows, decorative brick corning, and steam-powered pumping machinery.

Photographic documentation of the original structures has been recovered from archival sources. **Figure H-1** presents the filter building exterior as photographed by *Theodor Kofler* (Austrian photographer, active in Egypt 1903–1940s), estimated *ca.* 1910–1924. **Figure H-2** shows the original pump station building with its distinctive chimney stack; the royal Egyptian coat of arms confirms its official municipal status, and construction is attributed to J. Garozzo & Sons. **Figure H-3** presents the Google Earth aerial image (May 2011) of the plant in its pre-upgrading configuration.



**Figure H-1.** Filter building of El-Galaa WTP, Tanta, *ca.* 1910–1924. The neo-classical brick structure exhibits arched windows, Moorish-inspired decorative elements, and decorative corning characteristic of early twentieth-century Egyptian public works architecture. The mature garden setting suggests the photograph was taken some years after construction. Photograph: Theodor Kofler (Austrian photographer, active in Egypt 1903–1940s).



**Figure H-2.** Original pump station building of El-Galaa WTP, Tanta, early twentieth century. The steam chimney and royal Egyptian coat of arms (*upper right*) confirm the facility's official municipal character. A worker stands at the main entrance, providing scale. Construction is attributed to J. Garozzo & Sons.



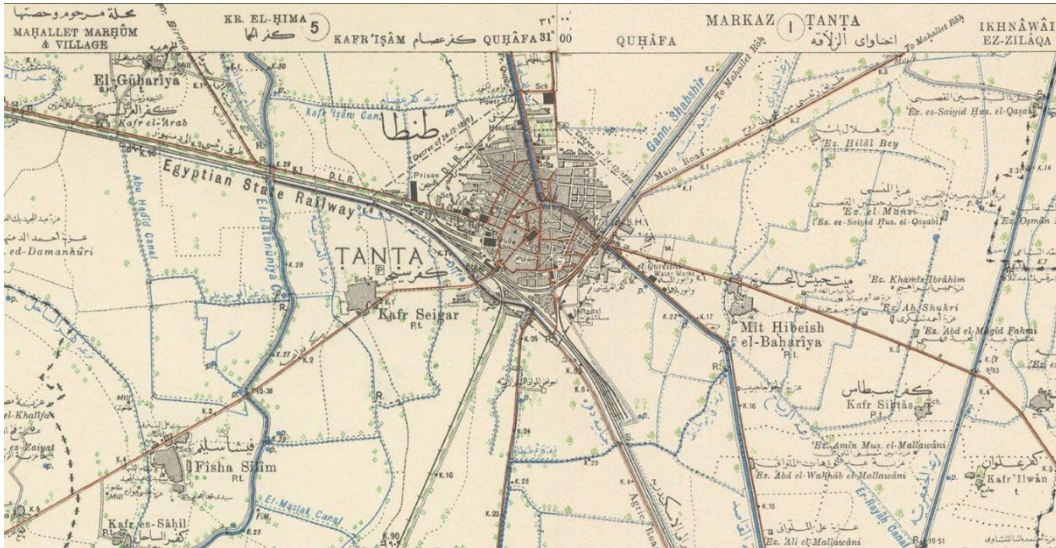
**Figure H-3.** Aerial satellite view of El-Galaa WTP, Tanta, prior to the 2019 modernization program. The image clearly shows the seven circular clari-flocculation units and six circular rapid sand filter vessels in their pre-upgrading configuration. The plant footprint and surrounding urban fabric are visible at 1:2,500 scale. Image source: Google Earth, image acquisition: May 2011, © Maxar Technologies.

## H.2 Cartographic Evidence

Historical cartographic records confirm the existence of water supply infrastructure at this site prior to the formal 1924 commissioning. The *Survey of Egypt* (1915) topographic map of Markaz Tanta (*Mudiriyet el-Gharbiya*) explicitly identifies the location as "Water Works" in the southeastern district of Tanta city, predating the formal establishment of the El-Galaa WTP. This evidence suggests that an earlier water

abstraction or distribution infrastructure may have existed on the same site before the 1924 formal commissioning, which may therefore represent a major expansion or formalization of pre-existing facilities rather than a greenfield development.

Cartographic reference: Survey of Egypt (1915). *Map of Markaz Tanta, Mudiriyet el-Gharbiya* [Cartographic material, 1:25,000]. Egyptian Survey Department. Available: Internet Archive, archive.org/details/Tantah [Accessed March 2026].



**Figure H-4.** Topographic map of Markaz Tanta, *Mudiriyet el-Gharbiya*, Egypt, scale 1:25,000. The annotation “Water Works” is visible in the southeastern quadrant of Tanta city, confirming the existence of water supply infrastructure at the El-Galaa WTP site as early as 1915 — nine years prior to the formal 1924 commissioning. Source: Survey of Egypt (1915); Internet Archive, archive.org/details/Tantah.

### H.3 Regional Context

The commissioning of El-Galaa WTP in 1924 was consistent with a broader programme of municipal water infrastructure development across the Gharbia Governorate during the early twentieth century. A comparable facility was established in the neighbouring city of **El-Mahalla El-Kubra** in **October 1925**, as evidenced by a foundation plaque installed during the reign of King **Fuad I** (r. 1917–1936), with engineering works supervised by Engineer **Mohamed Erfan Bek**. The proximity in commissioning dates and the shared architectural character of both facilities suggest a coordinated regional water supply programme under the municipal authority structure of the period.

The near-centenary of continuous operation prior to the 2019 modernization program — spanning approximately 95 years — underscores the engineering significance and public health importance of the upgrading works documented in the present study.

### H.4 Archival Sources

Table H-1 summarises the primary archival sources used in the historical documentation of El-Galaa WTP.

**Table H-1.** Archival sources for the historical documentation of El-Galaa WTP.

Reference	Description	Evidential Value	Source
<b>Figure H-1</b>	Filter building exterior, ca. 1910–1924	Confirms original architectural fabric of the WTP prior to any major modification	Photograph: Theodor Kofler (active in Egypt 1903–1940s)

Reference	Description	Evidential Value	Source
<b>Figure H-2</b>	Pump station with chimney stack and royal Egyptian coat of arms, early 20th century	Documents original pumping infrastructure and official municipal character of the facility	Municipal archive / attributed to J. Garozzo & Sons construction
<b>Figure H-3</b>	Google Earth aerial image of El-Galaa WTP, May 2011 (pre-upgrading)	Aerial documentation of plant configuration prior to the 2019 modernization	Google Earth / Maxar Technologies (image acquisition: May 2011)
<b>Survey of Egypt (1915)</b>	Topographic map of Markaz Tanta, Mudiriyet el-Gharbiya	Identifies "Water Works" at WTP site in 1915, predating the 1924 commissioning	Internet Archive: <a href="https://archive.org/details/Tantah">archive.org/details/Tantah</a>
<b>El-Mahalla WTP plaque</b>	Foundation inscription, October 1925 — reign of King Fuad I	Contextualises El-Galaa WTP within the regional water infrastructure programme of the 1920s	Field documentation; supervising engineer: Mohamed Erfan Bek

## Revised Manuscript Text for Section: Description of El-Galaa WTP

*Final revised paragraphs in response to Reviewer Comment 10 — ready for direct insertion into the manuscript.*

Figure 1 presents an aerial satellite image of the El-Galaa WTP prior to the modernization program, acquired from *Google Earth* (image acquisition: **May 2011**, © Maxar Technologies), while Figure 2 illustrates the plant layout in its original configuration. The treatment facility consisted of seven circular clari-flocculation units, six circular rapid sand filters, two ground-level treated water storage reservoirs, a low-lift pumping station, and auxiliary operational buildings. The plant was originally commissioned in **1924** under the municipal authority of Tanta City, with construction carried out by J. Garozzo & Sons, a contracting firm active in Egypt during the early twentieth century. The plant had not undergone any major structural refurbishment prior to the 2019 modernization program, representing approximately **95 years** of near-continuous operation prior to upgrading.

Figure 3 presents a representative clari-flocculation unit prior to upgrading. The reader's attention is directed to the visible sludge accumulation along the basin perimeter and the absence of mechanical flocculation equipment, both of which contributed to reduced hydraulic retention time and clarification inefficiency. Figure 4 shows the rapid sand filter building prior to rehabilitation, illustrating the six circular metallic filter vessels. Notable features include visible surface corrosion on the filter vessels and the absence of dedicated backwash pumping infrastructure, which necessitated manual high-pressure washing and contributed to inconsistent filter performance.

**Note to authors:** The Google Earth satellite image (Figure H-3 / Figure 1 in the main text) was acquired in May 2011. The caption should read: "Google Earth, image acquisition: May 2011, © Maxar Technologies."

## APPENDIX I

## Pre-Upgrade Raw Water Intake Structure

*El-Galaa Water Treatment Plant, Tanta, Gharbia Governorate, Egypt*

### I.1 Overview and Location

The pre-upgrade raw water intake system for El-Galaa Water Treatment Plant (WTP) was a gravity-fed masonry structure drawing water from El-Kased Canal via its El-Mahalla branch at Tanta. The intake was constructed as a brick masonry arch conduit approximately 1,000 m in length, connecting the canal abstraction point to the plant pump station. The system was designed to supply four centrifugal pumps with a combined installed capacity of  $600 \text{ L s}^{-1}$ , operating two units on duty and two on standby.

Reference Point	Latitude (N)	Longitude (E)
Intake point (canal junction)	30°46'24.61"	31°01'09.07"
Pump station (wet well)	30°46'44.87"	31°00'44.43"

### I.2 Geometric and Hydraulic Parameters

Table I-1 summarises the cross-sectional geometry of El-Kased Canal at the abstraction point.

Parameter	Value	Unit	Remarks
Canal type	Trapezoidal open channel	—	
Bank-to-bank width	34.00	m	Between earthen banks
Road crest elevation	+9.95	m	Local benchmark (□□□□□)
Design water surface elevation	+7.72	m	Local benchmark (□□□□□)
Canal bed elevation	+5.65	m	Local benchmark (□□□□□)
Design water depth	2.07	m	7.72 – 5.65 m
Freeboard	2.23	m	9.95 – 7.72 m
Seasonal water level variation	Variable	—	Subject to irrigation rotation

Table I-1. El-Kased Canal cross-sectional geometry at the raw water abstraction point (as-built survey, Gharbia Water and Wastewater Company, 2018).

Table I-2 presents the structural and hydraulic characteristics of the intake conduit and suction pipeline.

Parameter	Value	Unit	Remarks
Conduit type	<b>Brick masonry arch</b>	—	<i>Horseshoe profile</i>
Internal clear width	<b>1.00</b>	m	<i>As-built drawing</i>
Internal overall height	<b>~1.80</b>	m	<i>Including arch crown</i>
Total conduit length	<b>~1,000</b>	m	<i>Intake to pump station</i>
Intake invert elevation	<b>-8.00</b>	m	<i>Local benchmark (□□□□□)</i>
Benchmark reference	<b>Canal junction mouth</b>	—	<i>El-Mahalla branch x El-Kased Canal</i>
Suction pipeline material	<b>Reinforced concrete</b>	—	
Suction pipeline diameter	<b>Ø 1.50</b>	m	

Table I-2. Structural and hydraulic parameters of the pre-upgrade raw water intake conduit (as-built survey, Gharbia Water and Wastewater Company, 2018).

Table I-3 summarises the pre-upgrade pump station configuration at the receiving end of the intake conduit.

Parameter	Value	Unit	Remarks
Pump type	<b>Centrifugal</b>	—	
Number of units installed	<b>4</b>	—	
Duty / Standby arrangement	<b>2 / 2</b>	—	<i>N+1 standby redundancy</i>
Nominal capacity per pump	<b>150</b>	L s <sup>-1</sup>	
Total installed capacity	<b>600</b>	L s <sup>-1</sup>	<i>4 pumps combined</i>
Design duty capacity	<b>300</b>	L s <sup>-1</sup>	<i>2 pumps on duty</i>
Screening device	<b>Bar screen (manual)</b>	—	<i>Upstream of suction</i>

Table I-3. Pre-upgrade pump station configuration (as-built survey, Gharbia Water and Wastewater Company, 2018).

### I.3 As-Built Engineering Drawing

Figure I-1 presents the as-built plan and cross-sectional drawings of the pre-upgrade raw water intake system, as issued by the Gharbia Water and Wastewater Company. The drawing shows the full plan layout of the ~1,000 m intake conduit, together with three cross-sections: (a) the masonry arch conduit return tunnel, (b) the El-Kased Canal trapezoidal profile at the intake location, and (c) the Ø 1.50 m reinforced concrete suction pipeline.



Figure I-1. As-built engineering drawing of the pre-upgrade raw water intake system: plan view (top) and cross-sections of the masonry conduit, El-Kased Canal trapezoidal profile, and Ø 1.50 m suction pipeline (Gharbia Water and Wastewater Company, 2018).

### I.4 Annotated Cross-Sections

Figure I-2 provides enlarged views of the two key cross-sections extracted from the as-built drawing. The left panel shows the trapezoidal profile of El-Kased Canal at the intake location with annotated elevations (+9.95 m crest, +7.72 m water surface, +5.65 m bed). The right panel shows the brick masonry arch conduit cross-section (1.00 m internal width, ~1.80 m height) that formed the return tunnel conveying treated water from the pump station.

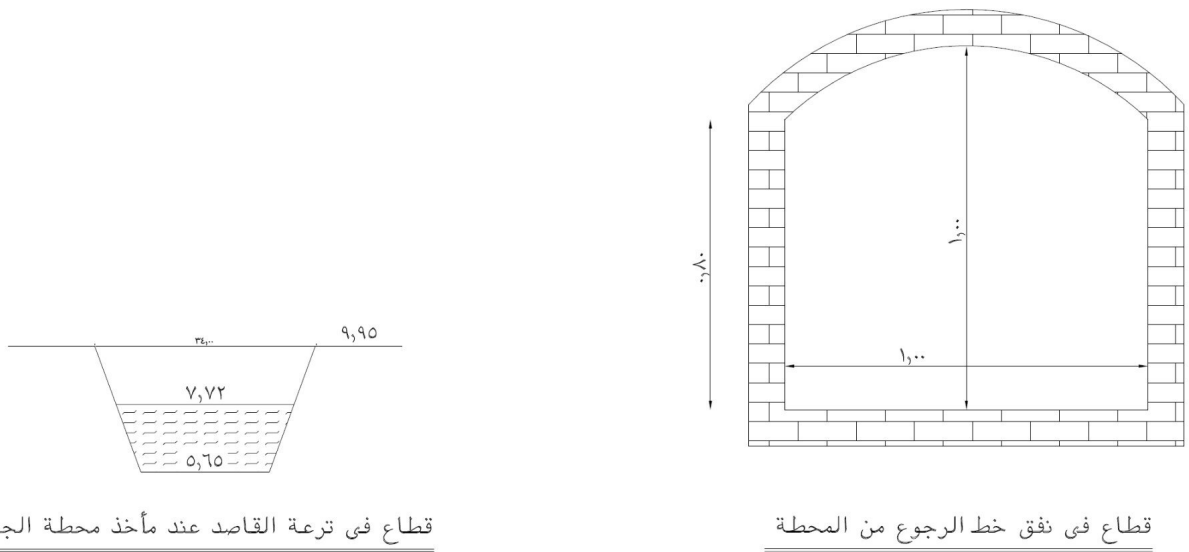


Figure I-2. Enlarged cross-sections from the as-built drawing: (left) El-Kased Canal trapezoidal profile with annotated elevations at the intake location; (right) brick masonry arch conduit cross-section (1.00 m x ~1.80 m) (Gharbia Water and Wastewater Company, 2018).

### I.5 Field Photographs

Figures I-3 and I-4 present field photographs documenting the pre-upgrade intake system and the El-Kased Canal at the abstraction location.



Figure I-3. Pre-upgrade centrifugal pump manifold arrangement at the El-Galaa WTP pump station. The photograph shows the deteriorated condition of the pump housings, discharge manifolds, and associated pipework prior to the 2019 rehabilitation programme (Field survey, 2018).



Figure I-4. El-Kased Canal at the raw water abstraction point, Tanta. The trapezoidal channel section shows the typical operational water level conditions. The intake structure for the post-upgrade system is visible on the left bank (Field survey, 2023).

## I.6 Documented Operational Limitations

The following operational deficiencies were systematically documented during the pre-upgrade condition assessment and constituted the primary technical justification for the comprehensive rehabilitation programme executed in 2019 (APHA-AWWA-WEF, 2017):

- (i) Frequent blockage of the manual bar screen under high-flow periods, resulting in reduced abstraction capacity and increased maintenance interventions.
- (ii) Sediment accumulation within the suction pipeline, directly attributable to the bottom-level intake position at canal bed elevation (invert at  $-8.00$  m), requiring periodic manual cleaning and causing unplanned operational downtime.
- (iii) Hydraulic instability arising from simultaneous operation of multiple pumping units, resulting in pressure fluctuations and reduced overall system efficiency.
- (iv) Insufficient conveyance capacity of the intake conduit relative to projected increases in potable water demand for the Tanta service area.

- (v) Absence of dedicated pre-treatment facilities (e.g., coarse screening, flow equalization) upstream of the primary treatment process, exposing downstream unit operations to uncontrolled raw water quality variations.

## I.7 Documentary Evidence and Data Sources

Document ID	Description	Source / Date
D-I-1	As-built engineering drawing: Plan and cross-sections of raw water intake	Gharbia WWSC, 2018
D-I-2	Field survey photographs: Pump manifold and canal conditions	El-Galaa WTP, 2018/2023
D-I-3	Benchmark (روبير) survey record: Canal junction mouth elevation	Gharbia WWSC, 2018
D-I-4	Operational assessment report: Pre-upgrade deficiencies	Gharbia WWSC, 2018

Table I-4. Documentary evidence register for Appendix I.

APHA-AWWA-WEF (2017). Standard Methods for the Examination of Water and Wastewater (23rd ed.). American Public Health Association, Washington, D.C.

# Appendix J

## Engineering Design Drawings & Technical Evidence

El-Galaa Water Treatment Plant — Post-Upgrade Project (2019)

Gharbia Water and Wastewater Company, Tanta, Egypt

**Version 4 · Figures J-1 to J-33 · Catalog Pages 1–102**

### **Total Engineering Drawings: 33 Figures**

Figures with Embedded Images: J-9 to J-33 (25 figures)

Figures from Catalog Pages 1–25: J-1 to J-8 (text descriptions — source catalog only)

**Source: Gharbia WWC (2020) — Official Engineering Design Catalog**

## J.0 Summary

This Appendix presents the complete set of engineering design drawings reproduced from the Official Engineering Design Catalog of El-Galaa Water Treatment Plant Post-Upgrade Project (Gharbia Water and Wastewater Company, 2020). The catalog, issued by the authority responsible for the 2019 upgrade, constitutes the primary engineering reference for all design parameters reported in Table 2 of the manuscript.

Appendix J Version 4 contains 33 figures (J-1 to J-33) drawn from catalog pages 1 through 102, providing multi-disciplinary documentary evidence spanning civil/structural, mechanical/process, and electrical/M&E engineering:

Figures	Catalog Pages	Discipline	Content
J-1 to J-8	1–13	<b>Administrative / Process</b>	Cover, contents, site layouts, P&ID, hydraulic diagrams, intake
J-9 to J-10	26–27	<b>Mechanical / Civil</b>	RSF building & pump station floor plans
J-11 to J-15	28–32	<b>Mechanical / Process</b>	Clari-flocculator plans and details
J-16 to J-22	33–39	<b>Civil / Structural</b>	RSF sections, filter media, chemical building
J-23 to J-24	47–50	<b>Electrical</b>	Sub-panel SLDs (first section)
J-25	73	<b>Mechanical</b>	RSF underdrain: 48 slabs / 54 nozzles
J-26 to J-29	78–90	<b>Structural</b>	Ground storage reservoir structural
J-30	96	<b>Structural</b>	Clari-flocculator reinforcement
J-31 to J-33	100–102	<b>Electrical / M&amp;E</b>	MDB SLD, raw water PS SLD, sub-panels

Note: Figures J-1 to J-8 originate from catalog pages 1–13, which are documented in the source catalog (Gharbia WWC, 2020) and are available upon request from the corresponding author. Images for J-9 to J-33 are embedded in this document, extracted from catalog PDF sections covering pages 26–102.

## Table of Figures (J-1 to J-33)

Figure	Title	Cat. Page	Section
J-1	<i>Official Engineering Catalog — Cover Page &amp; Project Identification</i>	1	J.1
J-2	<i>Engineering Catalog — Complete Table of Contents (100 Drawing Sheets)</i>	2	—
J-3	<i>Pre-Upgrade General Site Layout — Baseline Configuration</i>	3–6	J.2
J-4	<i>Post-Upgrade Site Layout — Colour-Coded Plan with Unit Count Table</i>	4	—
J-5	<i>Process &amp; Instrumentation Diagram (P&amp;ID) — Full Plant</i>	5	—
J-6	<i>As-Built General Site Layout with Dimension Annotations</i>	6	—
J-7	<i>Hydraulic Flow Diagram — Arabic Version</i>	7	—
J-8	<i>Intake Pipeline — Longitudinal Profile &amp; Construction Details</i>	8–13	—
J-9	RSF Building — High-Lift Pump Station & Chemical Equipment Floor Plan	26	J.3
J-10	RSF Building — Complete 8-Unit Filter Hall Floor Plan with Equipment	27	—
J-11	Clari-flocculator Complex — Multi-Unit Floor Plan (8 Cells Shown)	28	J.4
J-12	V-Notch Weir — 3D Illustration & Dimensional Cross-Sections	29	—
J-13	Clari-flocculator — Operational Details, Scrapers & Sludge System	30	—
J-14	Clari-flocculator — Vertical Sections & Tube Settler Module Details	31	—
J-15	Clari-flocculator — Top-Plan Showing Full Tube Settler Arrangement	32	—
J-16	RSF Building — Transverse Cross-Section A-A (Full Building Height)	33	J.5
J-17	RSF Building — Longitudinal Section B-B (Pipe Gallery & Valve Arrangement)	34	—
J-18	Chemical Dosing Building — Plan & Section: Alum and Chlorine Systems	35	—
J-19	RSF — Longitudinal Section: Complete Filter Media Profile (Depth = 110 cm)	36	—
J-20	RSF — Transverse Section: Filter Cell Internal Dimensions (6 m x 8 m)	37	—
J-21	RSF — Structural Reinforcement Details: Walls, Base Slab, Overflow Weir	38	—
J-22	Chemical Dosing System — Piping, Injection Points & Control Schematic	39	J.6
J-23	Sub-Panel SLD — Filter House & Ancillary Panel (First Section)	47	J.7
J-24	Sub-Panel SLD — Continuation: Additional Distribution Boards	50	—
J-25	RSF Underdrain — Layout: 48 Precast Slabs/Filter Bed, 54 Nozzles/Slab	73	J.8
J-26	Reservoir — Wall & Base Slab Structural Details with Water-Stop Joints	78	J.9
J-27	Reservoir — Structural Plan: Two-Compartment Layout (36x32 m Overall)	80	—
J-28	Inlet Distribution Box — Plan, Sections & Pipe Connection Details	84	—

Figure	Title	Cat. Page	Section
J-29	Reservoir — Full Structural Layout with Column Grid & Reinforcement Zones	90	—
J-30	Clari-flocculator — Circular Shell Reinforcement Details (Ø20 m Confirmed)	96	J.10
J-31	Main Distribution Board — Single-Line Diagram (2 × 2500 KVA, 5000 A Bus)	100	J.11
J-32	Raw Water Pumping Station — Low-Tension Switchboard SLD (2 × 800 KVA)	101	—
J-33	Sub-Panel SLDs — Five Panels: Filter, Pure Water, Wash Water, Sludge & Agitators	102	—

## Figure-to-Table 2 Relevance Map

The following table maps each figure in Appendix J to the specific parameters it documents in Table 2. Critical evidence figures are highlighted.

Figure(s)	Table 2 Unit	Parameters Evidenced
J-1 to J-2	Official Source Authority	Confirms Gharbia WWC (2020) as primary bibliographic reference
J-3 to J-4	All Units	Pre/post-upgrade unit counts; colour-coded site plan confirming Table 2 quantities
J-5	All Units	P&ID showing complete hydraulic train and instrumentation
J-6 to J-7	All Units	As-built layout and hydraulic flow diagram
J-8	Intake Structure	Ø1200 mm, 1000 m pipeline, 9 inspection chambers
J-9	High-Lift PS + Chemical	600 L/s design capacity, JESCO alum/chlorine dosing equipment
J-10	RSF (x8)	Unit count (8), cell dimensions 6x8 m, pipe gallery layout
J-11	Clari-flocculators (x3)	Three-unit plan, inlet Ø400 mm, effluent launders
J-12	Clari-flocculators (x3)	V-notch 60° angle, overflow weir geometry
J-13	Clari-flocculators (x3)	Inner Ø13.5 m confirmed, sludge scraper system
J-14	Clari-flocculators (x3)	Unit depth, tube settler elevation, overflow rate
J-15	Clari-flocculators (x3)	Full tube settler pack, Ø20m / Ø13.5m zones
J-16	RSF (x8)	Building height, backwash tank elevation
J-17	RSF (x8)	Pipe gallery full layout, valve arrangement
J-18	Chemical Dosing	Alum + chlorine building plan, JESCO equipment
J-19	RSF (x8)	★ Filter medium depth 110 cm — five-layer profile ★
J-20	RSF (x8)	Cell internal dimensions 6x8 m confirmed
J-21	RSF (x8)	Structural reinforcement of filter cells
J-22	Chemical Dosing	Dosing injection points, piping schematic
J-23 to J-24	Auxiliary Systems	Sub-panel SLDs: lighting, SCADA power, ancillaries
J-25	RSF (x8)	★ 48 precast slabs/filter, 54 nozzles/slab = 2,592 nozzles/unit ★
J-26 to J-29	Ground Storage Reservoirs	★ 36x32 m overall, two compartments 36x16x7 m, 4,000 m <sup>3</sup> each ★
J-30	Clari-flocculators (x3)	Ø20 m confirmed by structural drawings
J-31	High-Lift PS	2x2500 KVA, 5000 A bus, pump cubicle feeders
J-32	Intake / Raw Water PS	2x800 KVA, 6 pump cubicles, safe-starters
J-33	All Units (M&E)	5 sub-panels: RSF, pure water, wash water, sludge, agitators

## J.1 Project Identification & Catalog Authority

### Figure J-1 — Official Engineering Catalog — Cover Page & Project Identification

The cover page of the Official Engineering Design Catalog of El-Galaa Water Treatment Plant (محطة معالجة مياه الجلاء) confirms the issuing authority (Gharbia Water and Wastewater Company — شركة مياه الصرف الصحي الغربية), the project name (مشروع تطوير محطة معالجة مياه الجلاء بطنطا), and the year of issue (2020). This page constitutes the primary bibliographic source for citation (Gharbia WWC, 2020) as referenced throughout Table 2 and Appendix J.

#### [ Engineering Drawing — Catalog Page 1 ]

Source: Gharbia WWC (2020) — Official Engineering Catalog — Cover Page & Project Identification

Image available in source catalog (Gharbia WWC, 2020)

**Figure J-1.** Official Engineering Catalog — Cover Page & Project Identification [Catalog Page 1]

### Figure J-2 — Engineering Catalog — Complete Table of Contents (100 Drawing Sheets)

The catalog index lists all 100+ engineering drawing sheets contained within the official catalog, organised by discipline: civil/structural, mechanical/process, electrical/M&E. The index confirms that the drawings reproduced in Appendix J are an authentic subset of the complete engineering documentation package submitted to and approved by the responsible authority for the 2019 upgrade project.

#### [ Engineering Drawing — Catalog Page 2 ]

Source: Gharbia WWC (2020) — Engineering Catalog — Complete Table of Contents (100 Drawing Sheets)

Image available in source catalog (Gharbia WWC, 2020)

**Figure J-2.** Engineering Catalog — Complete Table of Contents (100 Drawing Sheets) [Catalog Page 2]

## J.2 Site Layouts & Process Diagrams (Catalog Pages 3–8)

### Figure J-3 — Pre-Upgrade General Site Layout — Baseline Configuration

General arrangement drawing of El-Galaa WTP prior to the 2019 upgrade, showing the original two clari-flocculators, old rapid sand filters, and original pump station. This drawing establishes the baseline for comparison with the post-upgrade configuration documented in Figure J-4, and substantiates the plant's founding date of 1924 and its historical operational context.

#### [ Engineering Drawing — Catalog Page 3–6 ]

Source: Gharbia WWC (2020) — Pre-Upgrade General Site Layout — Baseline Configuration

Image available in source catalog (Gharbia WWC, 2020)

**Figure J-3.** Pre-Upgrade General Site Layout — Baseline Configuration [Catalog Page 3–6]

### Figure J-4 — Post-Upgrade Site Layout — Colour-Coded Plan with Unit Count Table

Colour-coded general arrangement of the upgraded plant (2019) showing all new and retained structures. An embedded table on the drawing confirms: 3 clari-flocculators (×1 retained + ×2 new), 8 rapid sand filters (×4 retained + ×4 new), 2 ground storage reservoirs, 1 high-lift pump station (upgraded), 1 chemical dosing building (new), 1 intake structure. This is the most direct visual corroboration of the unit counts reported in Table 2.

#### [ Engineering Drawing — Catalog Page 4 ]

Source: Gharbia WWC (2020) — Post-Upgrade Site Layout — Colour-Coded Plan with Unit Count Table

Image available in source catalog (Gharbia WWC, 2020)

**Figure J-4.** Post-Upgrade Site Layout — Colour-Coded Plan with Unit Count Table [Catalog Page 4]

### Figure J-5 — Process & Instrumentation Diagram (P&ID) — Full Plant

The complete P&ID (مخطط P&I) shows the full hydraulic train from the Ø1200 mm intake pipeline at the Nile bank through the three clari-flocculators, eight rapid sand filters, ground storage reservoirs, and high-lift pump station to the Ø800 mm delivery main. The diagram includes all instrumentation, control valves, SCADA connection points, and dosing injection locations for alum and chlorine.

#### [ Engineering Drawing — Catalog Page 5 ]

Source: Gharbia WWC (2020) — Process & Instrumentation Diagram (P&ID) — Full Plant

Image available in source catalog (Gharbia WWC, 2020)

**Figure J-5.** Process & Instrumentation Diagram (P&ID) — Full Plant [Catalog Page 5]

### Figure J-6 — As-Built General Site Layout with Dimension Annotations

Final as-built site plan with overall site dimensions, setback distances, and building footprints annotated. The drawing shows the spatial relationship between the clari-flocculators (northern zone), RSF building (central zone), ground storage reservoirs (southern zone), and high-lift pump station.

#### [ Engineering Drawing — Catalog Page 6 ]

Source: Gharbia WWC (2020) — As-Built General Site Layout with Dimension Annotations

Image available in source catalog (Gharbia WWC, 2020)

**Figure J-6.** As-Built General Site Layout with Dimension Annotations [Catalog Page 6]

### Figure J-7 — Hydraulic Flow Diagram — Arabic Version

Arabic-language hydraulic flow diagram showing the complete treatment sequence: Raw water intake → Pre-chlorination → Alum dosing (flash mix) → Clari-flocculators → Rapid sand filters → Post-chlorination → Ground storage → High-lift pumping → Distribution. Flow arrows, pipe diameters, and key control points are annotated.

#### [ Engineering Drawing — Catalog Page 7 ]

Source: Gharbia WWC (2020) — Hydraulic Flow Diagram — Arabic Version

Image available in source catalog (Gharbia WWC, 2020)

**Figure J-7.** Hydraulic Flow Diagram — Arabic Version [Catalog Page 7]

### Figure J-8 — Intake Pipeline — Longitudinal Profile & Construction Details

Longitudinal profile of the Ø1200 mm reinforced concrete intake pipeline from the Nile bank to the plant inlet, showing the 1000 m horizontal length, hydraulic grade line, pipe invert elevations, and positions of the nine inspection/valving chambers. The drawing confirms the key intake parameters reported in Table 2: pipeline diameter Ø1200 mm, length 1000 m, and 9 inspection chambers.

#### [ Engineering Drawing — Catalog Page 8–13 ]

Source: Gharbia WWC (2020) — Intake Pipeline — Longitudinal Profile & Construction Details

Image available in source catalog (Gharbia WWC, 2020)

**Figure J-8.** Intake Pipeline — Longitudinal Profile & Construction Details [Catalog Page 8–13]

### J.3 RSF Building — Floor Plans & Equipment Layout

#### Figure J-9 — RSF Building — High-Lift Pump Station & Chemical Equipment Floor Plan

Combined floor plan of the high-lift pump station hall and the adjacent chemical dosing building, drawn at catalogue page 26. The drawing shows the four high-lift pumps (combined design capacity 600 L/s), the Ø800 mm discharge manifold, alum dosing JESCO metering pumps (2×990 L/s + 1×600 L/s), chlorine JESCO TOPAX DE dosing system, and the SCADA control panel layout. This confirms the high-lift pump station design capacity and chemical dosing infrastructure reported in Table 2.







## J.4 Clari-flocculators — Process & Structural Details

### Figure J-11 — Clari-flocculator Complex — Multi-Unit Floor Plan (8 Cells Shown)

Plan view of the complete clari-flocculator zone at catalog page 28, showing all three circular units to scale with their surrounding access platforms, inlet pipe connections ( $\text{Ø}400$  mm each), effluent collection launders, sludge draw-off points, and chemical dosing injection points. The drawing confirms three-unit configuration and individual unit dimensions consistent with Table 2.





### **Figure J-13 — Clari-flocculator — Operational Details, Scrapers & Sludge System**

Detailed drawings of the clari-flocculator's rotating sludge scraper mechanism, sludge hopper, and blow-off pipe arrangement. Also shows the inner cylinder (Ø13.5 m) feed inlet, diffuser plate, and upflow distribution system. Confirms the inner-to-outer diameter ratio (13.5 m / 20 m) and the sludge management configuration.

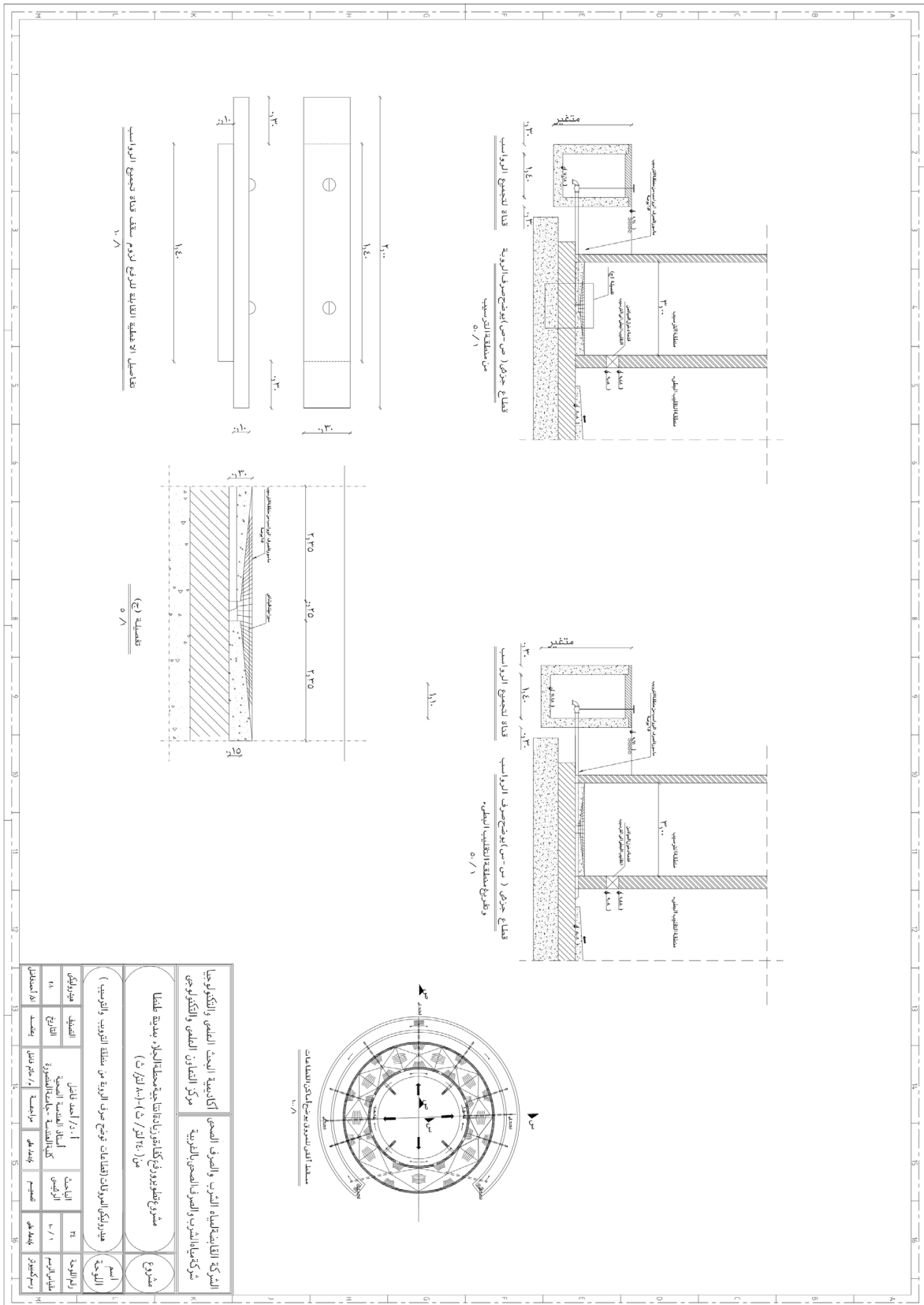


Figure J-14 — Clari-flocculator — Vertical Sections & Tube Settler Module Details



### **Figure J-15 — Clari-flocculator — Top-Plan Showing Full Tube Settler Arrangement**

Large-format plan view of a single clari-flocculator from above, clearly showing the complete honeycomb arrangement of inclined tube settlers within the annular zone between the inner cylinder (Ø13.5 m) and the outer wall (Ø20 m). The plan shows the radial access walkways, launder positions, and tube-settler pack extent. Confirms 60° inclination direction and full coverage area.

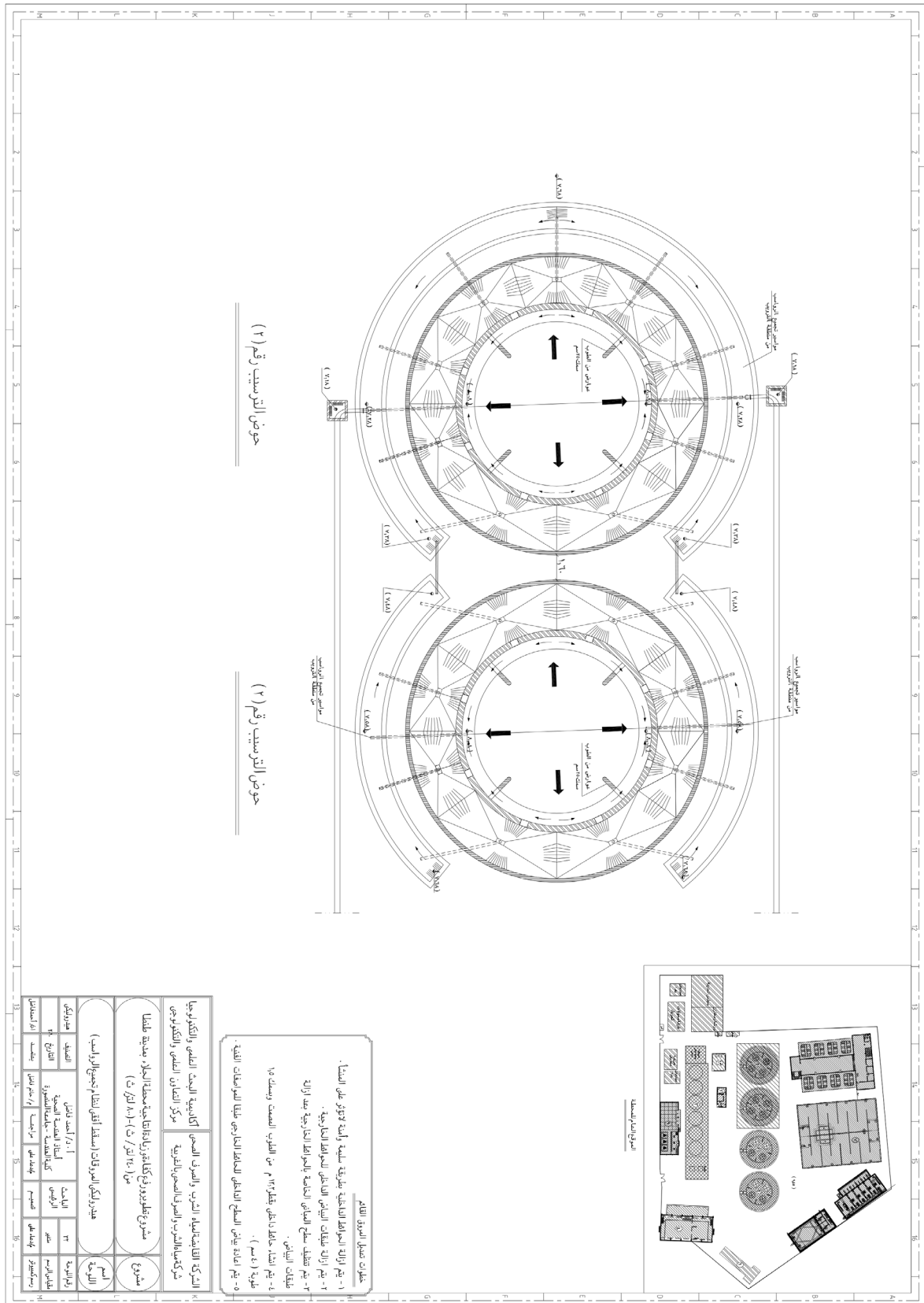


Figure J-15. Clari-flocculator — Top-Plan Showing Full Tube Settler Arrangement [Catalog Page 32]

## J.5 RSF — Cross-Sections & Filter Media Documentation

### Figure J-16 — RSF Building — Transverse Cross-Section A-A (Full Building Height)

Transverse section A-A through the full width of the rapid sand filter building, showing the structural walls, filter cell openings, overhead pipe runs, backwash water overhead tank, air-scour pipework, and roof structure. The section height confirms the internal clear-height of the filter cells and the elevation of key hydraulic components.







**Figure J-18.** Chemical Dosing Building — Plan & Section: Alum and Chlorine Systems [Catalog Page 35]

**Figure J-19 — RSF — Longitudinal Section: Complete Filter Media Profile (Depth = 110 cm)**

Primary documentary evidence for the 110 cm filter medium depth. This longitudinal section through a rapid sand filter cell shows the five-layer graded filter medium: fine sand (top) through coarse gravel (bottom), with cumulative depth annotations totalling 110 cm. Also shown: the concrete underdrain slab elevation, nozzle protrusion height above slab, overflow weir crest level, and hydraulic grades at design flow rate (ROF = 7.81 m/h).





### **Figure J-21 — RSF — Structural Reinforcement Details: Walls, Base Slab, Overflow Weir**

Reinforcement drawings for the RSF cell walls, base slab, overflow weir, and junction details. Bar schedules, cover dimensions, and concrete grade are specified. This structural documentation confirms the civil engineering basis for the filter cell dimensions and operating head reported in Table 2.

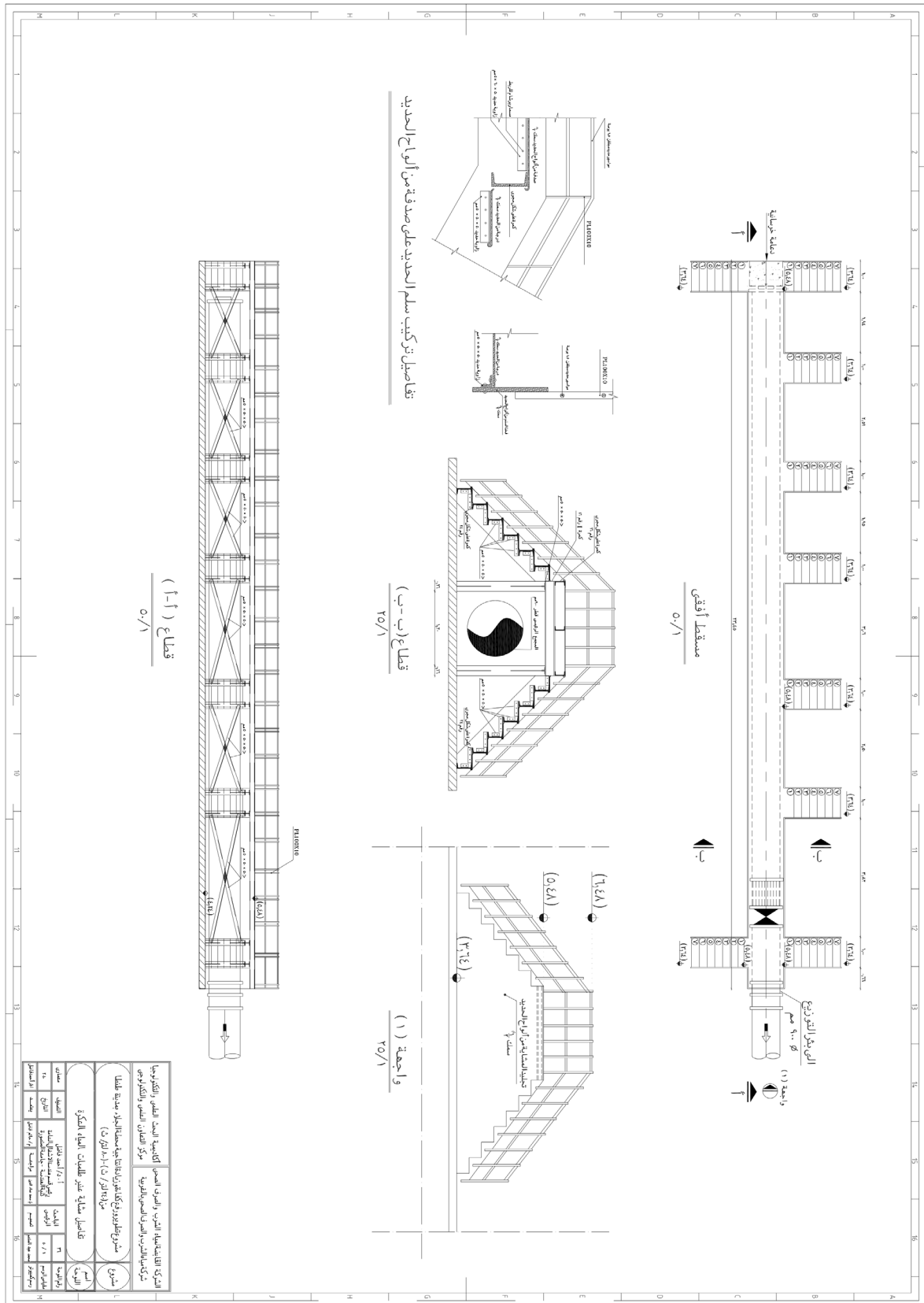


Figure J-21. RSF — Structural Reinforcement Details: Walls, Base Slab, Overflow Weir [Catalog Page 38]

## J.6 Chemical Dosing & Auxiliary Systems

### Figure J-22 — Chemical Dosing System — Piping, Injection Points & Control Schematic

Detailed piping schematic of the chemical dosing system showing alum (aluminium sulphate) and chlorine injection points, metering pump connections, flow control valves, and inline pH/turbidity monitoring. Confirms the dual-stage dosing strategy (pre-chlorination at intake + post-filtration chlorination) and the JESCO equipment cited in the manuscript.



## **J.7 Electrical Distribution — Single-Line Diagrams (from Catalog Pages 47–50)**

### **Figure J-23 — Sub-Panel SLD — Filter House & Ancillary Panel (First Section)**

Single-line diagram for the filter house electrical sub-panel and ancillary distribution boards, showing MCCBs, DOL and soft-starters, and cable sizing. Part of the complete electrical documentation set for the post-upgrade plant.







## J.8 RSF Underdrain System — 48 Slabs / 54 Nozzles per Filter

### Figure J-25 — RSF Underdrain — Layout: 48 Precast Slabs/Filter Bed, 54 Nozzles/Slab

Plan drawing titled 'PLAN SHOWING COLUMNS & SHELF FOR SUPPORTING UNDERDRAIN SLABS & FIXING ARRANGEMENT UNDERDRAIN SLABS — SLABS QTY: 48 PER FILTER BED'. Detailed assembly drawings show three slab types (A, B, C) each with 54 nozzles. Total nozzle count per filter =  $48 \times 54 = 2,592$ . Total for all 8 filters = 20,736 nozzles. Scale 1:50. This is the primary documentary source for the underdrain nozzle specification in Table 2.

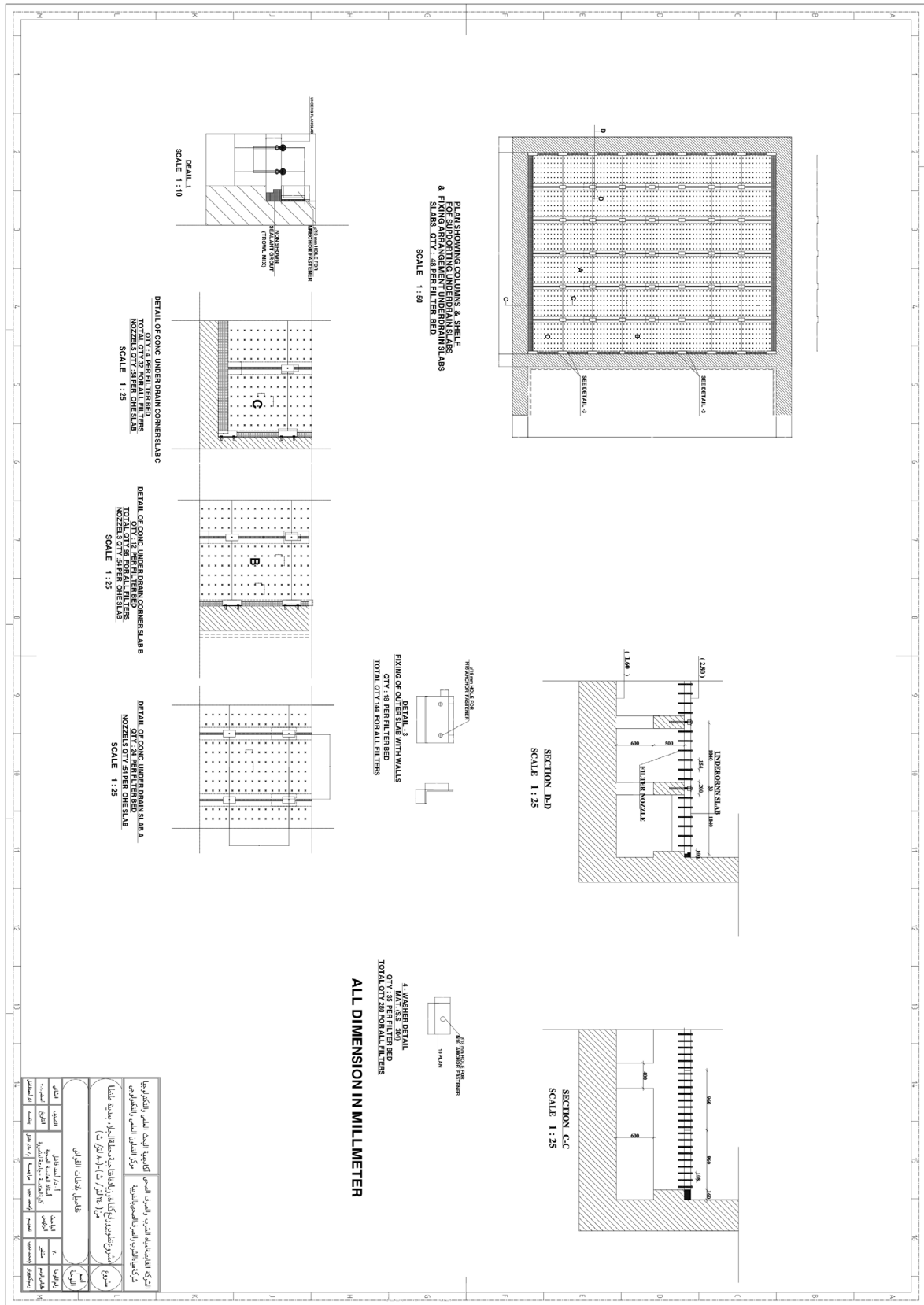


Figure J-25. RSF Underdrain — Layout: 48 Precast Slabs/Filter Bed, 54 Nozzles/Slab [Catalog Page 73] ★  
 Primary nozzle count evidence

## J.9 Ground Storage Reservoirs — Structural Documentation

### Figure J-26 — Reservoir — Wall & Base Slab Structural Details with Water-Stop Joints

Structural detail drawings for the reservoir wall-to-base slab junction, showing water-stop (نسيج مائي) joint construction, reinforcement bar arrangement, and concrete grade specification. The water-stop details confirm the watertight construction standard applied to the 36 × 32 m reservoir complex.

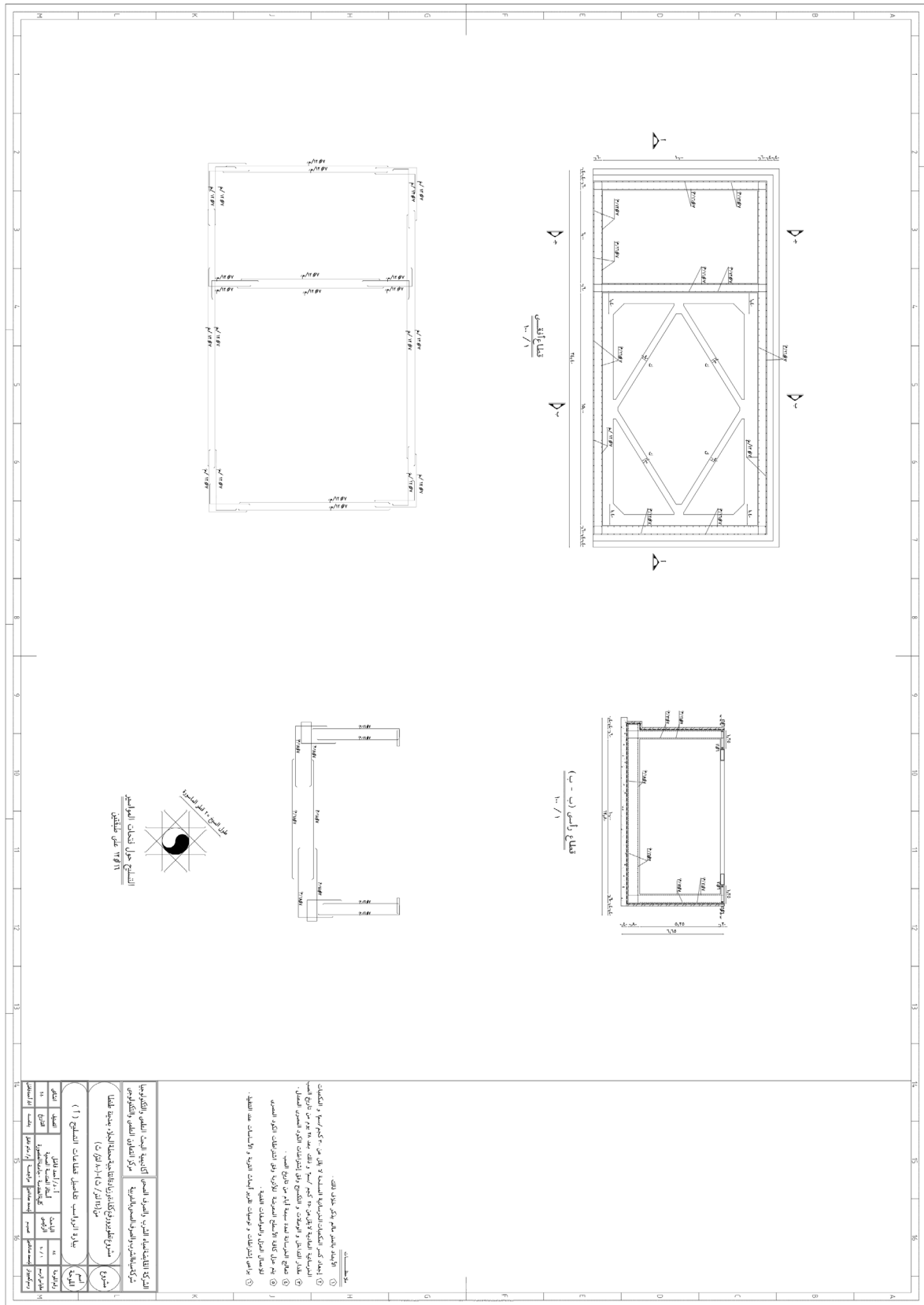


Figure J-26. Reservoir — Wall & Base Slab Structural Details with Water-Stop Joints [Catalog Page 78]

Figure J-27 — Reservoir — Structural Plan: Two-Compartment Layout (36x32 m Overall)



**Figure J-27.** Reservoir — Structural Plan: Two-Compartment Layout (36×32 m Overall) [Catalog Page 80] ★  
**Resolves reservoir dimension description**

### **Figure J-28 — Inlet Distribution Box — Plan, Sections & Pipe Connection Details**

Engineering drawings of the inlet distribution box (بئر التوزيع) which splits the filtered water flow from the RSF building into the two reservoir compartments. The drawing shows the box dimensions (8.55 × 4.75 × 3.30 m), the inlet pipe Ø900 mm, and the four outlet pipes Ø500 mm serving each compartment cell.



Complete structural layout drawing of the reservoir complex showing the column grid, construction joints, reinforcement zones, and access manhole positions. The column spacing and grid dimensions directly confirm the overall 36 x 32 m footprint and the internal compartment subdivision at 36 x 16 m.

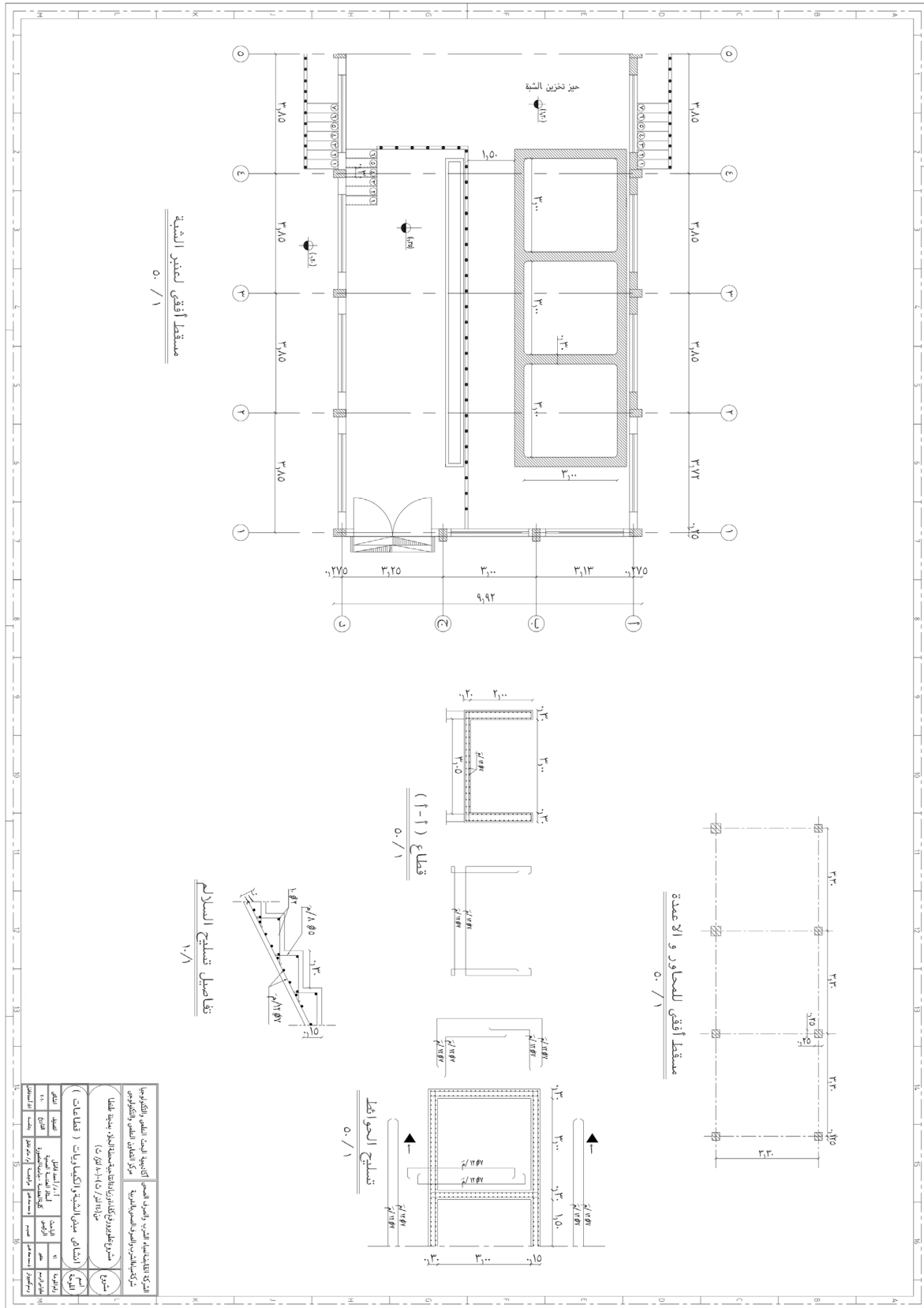


Figure J-29. Reservoir — Full Structural Layout with Column Grid & Reinforcement Zones [Catalog Page 90]



## J.10 Clari-flocculator — Structural Reinforcement Documentation

### Figure J-30 — Clari-flocculator — Circular Shell Reinforcement Details (Ø20 m Confirmed)

Structural reinforcement drawings for the circular clari-flocculator shell, confirming the outer diameter of 20 m through the reinforcement bar layout, hoop tension calculations, and wall section details. Bar sizes, spacing, splice lengths, and concrete cover are specified. This corroborates the Table 2 diameter through independent structural engineering documentation.



## **J.11 Electrical Single-Line Diagrams — Main Distribution (Catalog Pages 100–102)**

### **Figure J-31 — Main Distribution Board — Single-Line Diagram (2 × 2500 KVA, 5000 A Bus)**

Complete single-line diagram of the plant Main Distribution Board (MDB). Key specifications: two 2500 KVA, 11/0.4 kV power transformers (TR1 and TR2); 5000 A / 85 kA main bus; air circuit breakers (ACBs) on both sides; P.F. correction banks to achieve 0.95 p.f. lag; outgoing feeders to: wash water pump panel (3×2500 A), pure water pump panel (800 A), filter house panel (160 A), chlorine panel (60 A), alum panel (125 A), and site lighting. Provides electrical infrastructure evidence for the plant's 600 L/s design capacity.





### **Figure J-33 — Sub-Panel SLDs — Five Panels: Filter, Pure Water, Wash Water, Sludge & Agitators**

Composite drawing containing five electrical sub-panel single-line diagrams on a single sheet: (1) S.L.D for Filter House — filter desks, air compressor 10 hp, ventilating fans; (2) S.L.D for Pure Water Pumps — 6 pumps at 600/5 CT, 2(3×185+95) Cu, Air C.B 630 A; (3) S.L.D for Wash Water Pumping Panel — 2 wash pumps (3×400 A / 40 kA) + 2 air blowers (3×250 A / 35 kA); (4) S.L.D for Sludge Pumping Station — 3 sludge pumps (3×150 A / 35 kA) + 2 submersible pumps; (5) S.L.D for Agitators of Clarifiers — 5 agitator motors (3×25 A / 15 kA). Completes the full M&E documentation for all treatment units in Table 2.



## J.12 Suggested In-Text Citation

The following citation block should be used when referencing Table 2 and Appendix J in the manuscript body:

"All design parameters presented in Table 2 are derived from the Official Engineering Design Catalog of El-Galaa Water Treatment Plant (Gharbia Water and Wastewater Company, 2020). Supporting engineering drawings are reproduced in Appendix J (Figures J-1 to J-33), providing civil/structural, mechanical/process, and electrical/M&E documentary evidence for all treatment units listed. The complete catalog is available upon request from the corresponding author."

## J.13 Full Bibliographic Reference

Gharbia Water and Wastewater Company. (2020). Official Engineering Design Catalog — El-Galaa Water Treatment Plant Post-Upgrade Project [Engineering design drawings and technical specifications, 100+ sheets]. Gharbia Water and Wastewater Company, Tanta, Gharbia Governorate, Egypt. Available upon request from the corresponding author (M. [Author name], Gharbia WWC).

# APPENDIX K

## WAWQI Calculation Worksheets — Step-by-Step Evidence

El-Galaa Water Treatment Plant — Tanta, Egypt  
 Pre-Upgrade (2018) · Post-Upgrade (2019) · n = 31 samples each  
 Method: Ayoub (2017) — WAWQI | WHO (2011) Standards | K = 0.821993 |  $\Sigma W_n = 1.000$   
 Manuscript EEET-04501-2026-02 | Gharbia Water and Wastewater Company

### K-1 Calculation Methodology

This appendix provides full step-by-step WAWQI calculation worksheets for all 62 samples (31 pre-upgrade, 31 post-upgrade). For each sample, every intermediate value is shown: measured concentration ( $V_n$ ), quality rating ( $q_n$ ), unit weight ( $W_n$ ), and weighted sub-index ( $W_n \times q_n$ ). This satisfies the requirement for reproducible, auditable calculations per Ayoub (2017).

*NOTE:  $Ca^{2+}$  and  $Mg^{2+}$  concentrations were derived from Calcium Hardness (CaH) and Magnesium Hardness (MgH) measurements using stoichiometric conversion:  $Ca^{2+} = CaH \times (40.08/100.09)$ ;  $Mg^{2+} = MgH \times (24.305/100.09)$ .*

#### Equations:

$$WAWQI = \Sigma [ W_n \times q_n ] \quad (Eq. 1)$$

$$q_n = [(V_n - Vid) / (S_n - Vid)] \times 100 \quad (Eq. 2)$$

$$W_n = K / S_n \quad (Eq. 3)$$

$$K = 1 / \Sigma(1/S_n) = 0.821993 \rightarrow \Sigma W_n = 1.000000 \quad (Eq. 4)$$

Where:  $V_n$  = measured concentration;  $Vid$  = ideal value (0 for all except pH where  $Vid = 7.0$ );  $S_n$  = WHO (2011) permissible standard;  $W_n$  = unit weight.

Table K-1. WAWQI parameter weights: standard ( $S_n$ ), ideal ( $Vid$ ), K, unit weight ( $W_n = K/S_n$ ).  $K = 1/\Sigma(1/S_n) = 0.821993$ ;  $\Sigma W_n = 1.000000$ .

#	Parameter	Unit	$S_n$ (WHO 2011)	$Vid$	$W_n = K/S_n$	$W_n \times 1000$
1	Turbidity	NTU	1	0	0.821993	821.993
2	pH	—	8	7.0	0.102749	102.749
3	Total Hardness	mg/L	300	0	0.002740	2.740
4	Total Alkalinity	mg/L	120	0	0.006850	6.850
5	TDS	mg/L	500	0	0.001644	1.644
6	$Ca^{2+}$ (ion)	mg/L	75	0	0.010960	10.960
7	$Mg^{2+}$ (ion)	mg/L	30	0	0.027400	27.400
8	$Cl^-$	mg/L	250	0	0.003288	3.288
9	$SO_4^{2-}$	mg/L	200	0	0.004110	4.110
10	$NO_3^-$	mg/L	45	0	0.018267	18.267
	$\Sigma(1/S_n) = 1.216556$				$\rightarrow K = 0.821993$	$\Sigma W_n = 1.000000$

#### WQI Classification Scale (Ayoub, 2017):

WQI Range	Classification	Colour Code
0 – 25	Excellent	#00B050

26 – 50	Good	#00B0F0
51 – 75	Poor	#FFC000
76 – 100	Very Poor	#FF0000
> 100	Unsuitable for Drinking	#C00000

## K-2 Pre-Upgrade Treated Water — Calculation Worksheets (January–December 2018)

The following tables present the complete WAWQI calculation for each of the 31 pre-upgrade treated water samples. Ca<sup>2+</sup> and Mg<sup>2+</sup> are stoichiometrically derived from CaH and MgH (see Table K-2a footnote). All qn, Wn×qn, and WAWQI values are computed per Ayoub (2017).

Table K-2a. Measured concentrations (Vn). n = 31 samples.

No.	Date	Turb NTU	pH —	TH mg/L	TA mg/L	TDS mg/L	Ca <sup>2+</sup> mg/L	Mg <sup>2+</sup> mg/L	Cl <sup>-</sup> mg/L	SO <sub>4</sub> <sup>2-</sup> mg/L	NO <sub>3</sub> <sup>-</sup> mg/L
1	01 Jan 2018	0.82	7.29	208.00	166.00	361.00	52.06	18.94	42.00	43.60	2.35
2	15 Jan 2018	0.60	7.22	216.00	166.00	357.00	48.05	23.31	47.00	46.00	2.20
3	30 Jan 2018	0.59	7.22	216.00	162.00	382.00	50.46	21.85	39.00	42.00	2.50
4	10 Feb 2018	0.90	7.21	208.00	172.00	329.00	48.05	21.37	37.00	40.00	2.50
5	20 Feb 2018	0.50	7.24	192.00	152.00	272.00	49.65	16.51	39.00	43.30	2.60
6	28 Feb 2018	0.37	7.22	216.00	164.00	345.00	52.06	20.88	42.00	43.50	2.70
7	10 Mar 2018	0.55	7.25	230.00	160.00	293.00	56.86	21.37	46.00	48.00	2.40
8	20 Mar 2018	0.54	7.21	216.00	158.00	306.00	54.46	19.43	45.00	49.00	3.60
9	30 Mar 2018	0.72	7.16	230.00	164.00	304.00	59.27	19.91	44.00	44.20	2.60
10	10 Apr 2018	0.30	7.19	200.00	156.00	305.00	52.06	17.00	37.00	42.60	2.40
11	20 Apr 2018	0.40	7.21	226.00	164.00	327.00	59.27	18.94	41.00	40.50	2.50
12	30 Apr 2018	0.30	7.18	194.00	154.00	300.00	52.86	15.06	28.00	34.60	2.40
13	10 May 2018	0.69	7.21	216.00	168.00	312.00	52.06	20.88	34.00	30.40	2.10
14	20 May 2018	0.90	7.23	224.00	152.00	330.00	56.06	20.40	40.00	42.00	2.40
15	30 May 2018	1.00	7.17	170.00	140.00	235.00	48.05	12.14	25.00	26.40	2.40
16	10 Jun 2018	0.80	7.25	196.00	144.00	300.00	49.65	17.48	37.00	43.80	2.20
17	20 Jun 2018	0.65	7.25	200.00	136.00	274.00	48.05	19.43	27.00	40.60	2.00
18	30 Jun 2018	0.50	7.25	182.00	160.00	288.00	48.05	15.06	27.00	29.00	1.90
19	10 Jul 2018	0.90	7.21	160.00	145.00	248.00	42.45	13.11	24.00	26.80	4.00
20	20 Jul 2018	0.45	7.17	194.00	160.00	290.00	52.86	15.06	35.00	39.20	3.00
21	30 Jul 2018	0.80	7.32	174.00	160.00	277.00	44.85	15.06	40.00	34.60	2.70
22	10 Aug 2018	0.85	7.22	190.00	148.00	285.00	48.05	17.00	34.00	43.00	2.60
23	20 Aug 2018	0.60	7.36	214.00	160.00	310.00	54.46	18.94	31.00	36.20	2.10
24	30 Aug 2018	0.95	7.55	202.00	160.00	296.00	52.06	17.48	34.00	34.20	2.60
25	10 Sep 2018	1.00	7.54	218.00	172.00	328.00	56.06	18.94	34.00	44.50	2.20
26	25 Sep 2018	0.83	7.40	225.00	172.00	313.00	58.46	19.18	32.00	46.60	2.90
27	10 Oct 2018	0.85	7.41	184.00	148.00	302.00	53.66	16.51	32.00	43.00	2.30
28	25 Oct 2018	1.00	7.41	220.00	166.00	333.00	56.06	19.43	34.00	40.60	2.40
29	10 Nov 2018	1.00	7.43	210.00	162.00	341.00	52.86	18.94	38.00	44.90	2.40
30	25 Nov 2018	1.00	7.32	220.00	162.00	325.00	59.27	17.48	39.00	41.60	2.50
31	04 Dec 2018	1.00	7.43	216.00	156.00	314.00	56.06	17.97	39.00	46.00	2.50

Table K-2b. Quality ratings (qn = [(Vn-Vid)/(Sn-Vid)]×100). n = 31 samples.

No.	Date	Turb Wn×1000:	pH 821.99	TH 102.75	TA 2.74	TDS 6.85	Ca <sup>2+</sup> 1.64	Mg <sup>2+</sup> 10.96	Cl <sup>-</sup> 27.40	SO <sub>4</sub> <sup>2-</sup> 3.29	NO <sub>3</sub> <sup>-</sup> 4.11
1	01 Jan 2018	82.000	29.000	69.333	138.333	72.200	69.410	63.136	16.800	21.800	5.222
2	15 Jan 2018	60.000	22.000	72.000	138.333	71.400	64.070	77.706	18.800	23.000	4.889
3	30 Jan 2018	59.000	22.000	72.000	135.000	76.400	67.274	72.849	15.600	21.000	5.556
4	10 Feb 2018	90.000	21.000	69.333	143.333	65.800	64.070	71.231	14.800	20.000	5.556
5	20 Feb 2018	50.000	24.000	64.000	126.667	54.400	66.206	55.042	15.600	21.650	5.778
6	28 Feb 2018	37.000	22.000	72.000	136.667	69.000	69.410	69.612	16.800	21.750	6.000
7	10 Mar 2018	55.000	25.000	76.667	133.333	58.600	75.817	71.231	18.400	24.000	5.333
8	20 Mar 2018	54.000	21.000	72.000	131.667	61.200	72.613	64.755	18.000	24.500	8.000
9	30 Mar 2018	72.000	16.000	76.667	136.667	60.800	79.020	66.374	17.600	22.100	5.778
10	10 Apr 2018	30.000	19.000	66.667	130.000	61.000	69.410	56.661	14.800	21.300	5.333
11	20 Apr 2018	40.000	21.000	75.333	136.667	65.400	79.020	63.136	16.400	20.250	5.556
12	30 Apr 2018	30.000	18.000	64.667	128.333	60.000	70.477	50.185	11.200	17.300	5.333
13	10 May 2018	69.000	21.000	72.000	140.000	62.400	69.410	69.612	13.600	15.200	4.667
14	20 May 2018	90.000	23.000	74.667	126.667	66.000	74.749	67.993	16.000	21.000	5.333
15	30 May 2018	100.000	17.000	56.667	116.667	47.000	64.070	40.472	10.000	13.200	5.333
16	10 Jun 2018	80.000	25.000	65.333	120.000	60.000	66.206	58.280	14.800	21.900	4.889
17	20 Jun 2018	65.000	25.000	66.667	113.333	54.800	64.070	64.755	10.800	20.300	4.444
18	30 Jun 2018	50.000	25.000	60.667	133.333	57.600	64.070	50.185	10.800	14.500	4.222
19	10 Jul 2018	90.000	21.000	53.333	120.833	49.600	56.595	43.710	9.600	13.400	8.889

20	20 Jul 2018	45.000	17.000	64.667	133.333	58.000	70.477	50.185	14.000	19.600	6.667
21	30 Jul 2018	80.000	32.000	58.000	133.333	55.400	59.799	50.185	16.000	17.300	6.000
22	10 Aug 2018	85.000	22.000	63.333	123.333	57.000	64.070	56.661	13.600	21.500	5.778
23	20 Aug 2018	60.000	36.000	71.333	133.333	62.000	72.613	63.136	12.400	18.100	4.667
24	30 Aug 2018	95.000	55.000	67.333	133.333	59.200	69.410	58.280	13.600	17.100	5.778
25	10 Sep 2018	100.000	54.000	72.667	143.333	65.600	74.749	63.136	13.600	22.250	4.889
26	25 Sep 2018	83.000	40.000	75.000	143.333	62.600	77.952	63.946	12.800	23.300	6.444
27	10 Oct 2018	85.000	41.000	61.333	123.333	60.400	71.545	55.042	12.800	21.500	5.111
28	25 Oct 2018	100.000	41.000	73.333	138.333	66.600	74.749	64.755	13.600	20.300	5.333
29	10 Nov 2018	100.000	43.000	70.000	135.000	68.200	70.477	63.136	15.200	22.450	5.333
30	25 Nov 2018	100.000	32.000	73.333	135.000	65.000	79.020	58.280	15.600	20.800	5.556
31	04 Dec 2018	100.000	43.000	72.000	130.000	62.800	74.749	59.898	15.600	23.000	5.556

Table K-2c. Weighted sub-indices (Wn x qn). n = 31 samples.

No.	Date	Turb	pH	TH	TA	TDS	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>
		<b>Wn:</b>	<b>0.82199</b>	<b>0.10275</b>	<b>0.00274</b>	<b>0.00685</b>	<b>0.00164</b>	<b>0.01096</b>	<b>0.02740</b>	<b>0.00329</b>	<b>0.00411</b>
1	01 Jan 2018	67.4034	2.9797	0.1900	0.9476	0.1187	0.7607	1.7299	0.0552	0.0896	0.0954
2	15 Jan 2018	49.3196	2.2605	0.1973	0.9476	0.1174	0.7022	2.1291	0.0618	0.0945	0.0893
3	30 Jan 2018	48.4976	2.2605	0.1973	0.9247	0.1256	0.7373	1.9961	0.0513	0.0863	0.1015
4	10 Feb 2018	73.9794	2.1577	0.1900	0.9818	0.1082	0.7022	1.9517	0.0487	0.0822	0.1015
5	20 Feb 2018	41.0996	2.4660	0.1754	0.8677	0.0894	0.7256	1.5081	0.0513	0.0890	0.1055
6	28 Feb 2018	30.4137	2.2605	0.1973	0.9362	0.1134	0.7607	1.9073	0.0552	0.0894	0.1096
7	10 Mar 2018	45.2096	2.5687	0.2101	0.9133	0.0963	0.8309	1.9517	0.0605	0.0986	0.0974
8	20 Mar 2018	44.3876	2.1577	0.1973	0.9019	0.1006	0.7958	1.7743	0.0592	0.1007	0.1461
9	30 Mar 2018	59.1835	1.6440	0.2101	0.9362	0.1000	0.8661	1.8186	0.0579	0.0908	0.1055
10	10 Apr 2018	24.6598	1.9522	0.1827	0.8905	0.1003	0.7607	1.5525	0.0487	0.0875	0.0974
11	20 Apr 2018	32.8797	2.1577	0.2064	0.9362	0.1075	0.8661	1.7299	0.0539	0.0832	0.1015
12	30 Apr 2018	24.6598	1.8495	0.1772	0.8791	0.0986	0.7724	1.3751	0.0368	0.0711	0.0974
13	10 May 2018	56.7175	2.1577	0.1973	0.9590	0.1026	0.7607	1.9073	0.0447	0.0625	0.0852
14	20 May 2018	73.9794	2.3632	0.2046	0.8677	0.1085	0.8192	1.8630	0.0526	0.0863	0.0974
15	30 May 2018	82.1993	1.7467	0.1553	0.7992	0.0773	0.7022	1.1089	0.0329	0.0543	0.0974
16	10 Jun 2018	65.7594	2.5687	0.1790	0.8220	0.0986	0.7256	1.5968	0.0487	0.0900	0.0893
17	20 Jun 2018	53.4295	2.5687	0.1827	0.7763	0.0901	0.7022	1.7743	0.0355	0.0834	0.0812
18	30 Jun 2018	41.0996	2.5687	0.1662	0.9133	0.0947	0.7022	1.3751	0.0355	0.0596	0.0771
19	10 Jul 2018	73.9794	2.1577	0.1461	0.8277	0.0815	0.6203	1.1976	0.0316	0.0551	0.1624
20	20 Jul 2018	36.9897	1.7467	0.1772	0.9133	0.0954	0.7724	1.3751	0.0460	0.0806	0.1218
21	30 Jul 2018	65.7594	3.2880	0.1589	0.9133	0.0911	0.6554	1.3751	0.0526	0.0711	0.1096
22	10 Aug 2018	69.8694	2.2605	0.1735	0.8448	0.0937	0.7022	1.5525	0.0447	0.0884	0.1055
23	20 Aug 2018	49.3196	3.6990	0.1955	0.9133	0.1019	0.7958	1.7299	0.0408	0.0744	0.0852
24	30 Aug 2018	78.0893	5.6512	0.1845	0.9133	0.0973	0.7607	1.5968	0.0447	0.0703	0.1055
25	10 Sep 2018	82.1993	5.5485	0.1991	0.9818	0.1078	0.8192	1.7299	0.0447	0.0914	0.0893
26	25 Sep 2018	68.2254	4.1100	0.2055	0.9818	0.1029	0.8543	1.7521	0.0421	0.0958	0.1177
27	10 Oct 2018	69.8694	4.2127	0.1681	0.8448	0.0993	0.7841	1.5081	0.0421	0.0884	0.0934
28	25 Oct 2018	82.1993	4.2127	0.2009	0.9476	0.1095	0.8192	1.7743	0.0447	0.0834	0.0974
29	10 Nov 2018	82.1993	4.4182	0.1918	0.9247	0.1121	0.7724	1.7299	0.0500	0.0923	0.0974
30	25 Nov 2018	82.1993	3.2880	0.2009	0.9247	0.1069	0.8661	1.5968	0.0513	0.0855	0.1015
31	04 Dec 2018	82.1993	4.4182	0.1973	0.8905	0.1032	0.8192	1.6412	0.0513	0.0945	0.1015

Table K-2d. Final WAWQI per sample and classification. Distribution: Excellent=0 (0%) Good=7 (23%) Poor=11 (35%) Very Poor=13 (42%)

No.	Date	WAWQI	Classification
	Ayoub (2017)	<b>Mean=66.07±19.36</b>	[30.15 – 92.04]
1	01 Jan 2018	<b>74.37</b>	<b>Poor</b>
2	15 Jan 2018	<b>55.92</b>	<b>Poor</b>
3	30 Jan 2018	<b>54.98</b>	<b>Poor</b>
4	10 Feb 2018	<b>80.30</b>	<b>Very Poor</b>
5	20 Feb 2018	<b>47.18</b>	<b>Good</b>
6	28 Feb 2018	<b>36.84</b>	<b>Good</b>
7	10 Mar 2018	<b>52.04</b>	<b>Poor</b>
8	20 Mar 2018	<b>50.62</b>	<b>Poor</b>
9	30 Mar 2018	<b>65.01</b>	<b>Poor</b>
10	10 Apr 2018	<b>30.33</b>	<b>Good</b>
11	20 Apr 2018	<b>39.12</b>	<b>Good</b>
12	30 Apr 2018	<b>30.15</b>	<b>Good</b>
13	10 May 2018	<b>62.99</b>	<b>Poor</b>
14	20 May 2018	<b>80.44</b>	<b>Very Poor</b>
15	30 May 2018	<b>86.97</b>	<b>Very Poor</b>
16	10 Jun 2018	<b>71.98</b>	<b>Poor</b>
17	20 Jun 2018	<b>59.72</b>	<b>Poor</b>

18	30 Jun 2018	47.09	Good
19	10 Jul 2018	79.26	Very Poor
20	20 Jul 2018	42.32	Good
21	30 Jul 2018	72.47	Poor
22	10 Aug 2018	75.74	Very Poor
23	20 Aug 2018	56.96	Poor
24	30 Aug 2018	87.51	Very Poor
25	10 Sep 2018	92.04	Very Poor
26	25 Sep 2018	76.49	Very Poor
27	10 Oct 2018	77.71	Very Poor
28	25 Oct 2018	90.49	Very Poor
29	10 Nov 2018	90.59	Very Poor
30	25 Nov 2018	89.42	Very Poor
31	04 Dec 2018	90.52	Very Poor

### K-3 Post-Upgrade Treated Water — Calculation Worksheets (January–September 2019)

The following tables present the complete WAWQI calculation for each of the 31 post-upgrade treated water samples. Same methodology and parameter weights as K-2.

Table K-3a. Measured concentrations (Vn). n = 31 samples.

No.	Date	Turb	pH	TH	TA	TDS	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>
		NTU	—	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	15 Jan 2019	0.10	7.25	180.00	142.00	245.90	48.08	14.56	24.00	28.90	2.20
2	20 Jan 2019	0.20	7.30	167.00	140.00	235.90	44.60	13.50	25.40	33.00	2.10
3	25 Jan 2019	0.25	7.22	170.00	142.00	238.50	45.41	13.75	24.00	39.90	2.10
4	10 Feb 2019	0.20	7.21	162.00	140.00	237.40	43.27	13.10	24.00	34.00	1.90
5	20 Feb 2019	0.11	7.40	170.00	148.00	296.80	46.83	12.88	26.00	29.00	2.10
6	28 Feb 2019	0.10	7.30	190.00	138.00	304.20	50.48	15.53	23.00	32.50	1.60
7	10 Mar 2019	0.15	7.25	194.00	128.00	245.90	51.87	15.65	24.00	30.00	1.80
8	20 Mar 2019	0.30	7.21	200.00	152.00	294.20	53.42	16.17	27.00	31.60	1.60
9	31 Mar 2019	0.35	7.23	166.00	132.00	252.80	44.29	13.45	26.00	32.30	1.30
10	05 Apr 2019	0.30	7.19	180.00	132.00	227.90	48.08	14.56	23.00	29.30	1.80
11	15 Apr 2019	0.30	7.21	184.00	134.00	224.70	49.07	14.92	24.00	31.60	1.00
12	25 Apr 2019	0.30	7.18	175.00	130.00	237.40	46.72	14.16	26.00	34.60	1.60
13	30 Apr 2019	0.20	7.21	180.00	140.00	259.70	48.08	14.56	21.00	30.40	1.70
14	05 May 2019	0.17	7.23	166.00	125.00	234.30	44.29	13.45	23.00	26.40	1.60
15	05 May 2019	0.25	7.17	162.00	138.00	233.20	43.27	13.10	25.00	25.60	1.40
16	15 May 2019	0.30	7.25	168.00	132.00	234.30	44.94	13.55	26.00	25.80	1.40
17	25 May 2019	0.27	7.25	170.00	122.00	210.90	45.41	13.75	25.00	29.00	2.00
18	05 Jun 2019	0.12	7.25	210.00	134.00	203.50	60.13	14.53	27.00	26.80	1.70
19	10 Jun 2019	0.15	7.21	212.00	138.00	201.90	60.33	14.90	24.00	26.80	1.90
20	20 Jun 2019	0.20	7.17	212.00	142.00	207.80	60.33	14.90	24.00	29.60	2.00
21	30 Jun 2019	0.30	7.32	210.00	134.00	217.30	60.13	14.53	23.00	30.60	1.90
22	05 Jul 2019	0.16	7.22	200.00	135.00	222.60	53.42	16.17	25.00	26.70	1.60
23	15 Jul 2019	0.10	7.30	204.00	136.00	220.50	54.56	16.45	26.00	27.50	1.80
24	25 Jul 2019	0.10	7.23	200.00	132.00	225.20	53.42	16.17	26.00	30.60	1.50
25	31 Jul 2019	0.20	7.18	194.00	138.00	199.80	51.87	15.65	28.00	28.70	1.80
26	05 Aug 2019	0.25	7.20	220.00	142.00	203.50	58.90	17.70	27.00	30.60	1.70
27	15 Aug 2019	0.23	7.25	190.00	160.00	224.70	50.83	15.31	27.00	30.00	1.60
28	25 Aug 2019	0.21	7.28	200.00	150.00	197.70	53.42	16.17	24.00	29.00	1.90
29	01 Sep 2019	0.05	7.32	190.00	142.00	199.80	50.83	15.31	26.00	26.20	1.80
30	10 Sep 2019	0.17	7.28	200.00	140.00	277.20	53.42	16.17	29.00	24.90	2.00
31	20 Sep 2019	0.26	7.43	193.00	132.00	227.90	51.52	15.62	27.00	26.30	1.40

Table K-3b. Quality ratings (qn = [(Vn-Vid)/(Sn-Vid)]x100). n = 31 samples.

No.	Date	Turb	pH	TH	TA	TDS	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>
		Wn×1000:	821.99	102.75	2.74	6.85	1.64	10.96	27.40	3.29	4.11
1	15 Jan 2019	10.000	25.000	60.000	118.333	49.180	64.102	48.518	9.600	14.450	4.889
2	20 Jan 2019	20.000	30.000	55.667	116.667	47.180	59.473	45.013	10.160	16.500	4.667
3	25 Jan 2019	25.000	22.000	56.667	118.333	47.700	60.541	45.822	9.600	19.950	4.667
4	10 Feb 2019	20.000	21.000	54.000	116.667	47.480	57.690	43.669	9.600	17.000	4.222
5	20 Feb 2019	11.000	40.000	56.667	123.333	59.360	62.437	42.949	10.400	14.500	4.667
6	28 Feb 2019	10.000	30.000	63.333	115.000	60.840	67.306	51.755	9.200	16.250	3.556
7	10 Mar 2019	15.000	25.000	64.667	106.667	49.180	69.164	52.176	9.600	15.000	4.000

8	20 Mar 2019	30.000	21.000	66.667	126.667	58.840	71.225	53.909	10.800	15.800	3.556
9	31 Mar 2019	35.000	23.000	55.333	110.000	50.560	59.057	44.835	10.400	16.150	2.889
10	05 Apr 2019	30.000	19.000	60.000	110.000	45.580	64.102	48.518	9.200	14.650	4.000
11	15 Apr 2019	30.000	21.000	61.333	111.667	44.940	65.432	49.740	9.600	15.800	2.222
12	25 Apr 2019	30.000	18.000	58.333	108.333	47.480	62.292	47.215	10.400	17.300	3.556
13	30 Apr 2019	20.000	21.000	60.000	116.667	51.940	64.102	48.518	8.400	15.200	3.778
14	05 May 2019	17.000	23.000	55.333	104.167	46.860	59.057	44.835	9.200	13.200	3.556
15	05 May 2019	25.000	17.000	54.000	115.000	46.640	57.690	43.669	10.000	12.800	3.111
16	15 May 2019	30.000	25.000	56.000	110.000	46.860	59.916	45.150	10.400	12.900	3.111
17	25 May 2019	27.000	25.000	56.667	101.667	42.180	60.541	45.822	10.000	14.500	4.444
18	05 Jun 2019	12.000	25.000	70.000	111.667	40.700	80.168	48.445	10.800	13.400	3.778
19	10 Jun 2019	15.000	21.000	70.667	115.000	40.380	80.435	49.659	9.600	13.400	4.222
20	20 Jun 2019	20.000	17.000	70.667	118.333	41.560	80.435	49.659	9.600	14.800	4.444
21	30 Jun 2019	30.000	32.000	70.000	111.667	43.460	80.168	48.445	9.200	15.300	4.222
22	05 Jul 2019	16.000	22.000	66.667	112.500	44.520	71.225	53.909	10.000	13.350	3.556
23	15 Jul 2019	10.000	30.000	68.000	113.333	44.100	72.747	54.839	10.400	13.750	4.000
24	25 Jul 2019	10.000	23.000	66.667	110.000	45.040	71.225	53.909	10.400	15.300	3.333
25	31 Jul 2019	20.000	18.000	64.667	115.000	39.960	69.164	52.176	11.200	14.350	4.000
26	05 Aug 2019	25.000	20.000	73.333	118.333	40.700	78.540	59.008	10.800	15.300	3.778
27	15 Aug 2019	23.000	25.000	63.333	133.333	44.940	67.776	51.043	10.800	15.000	3.556
28	25 Aug 2019	21.000	28.000	66.667	125.000	39.540	71.225	53.909	9.600	14.500	4.222
29	01 Sep 2019	5.000	32.000	63.333	118.333	39.960	67.776	51.043	10.400	13.100	4.000
30	10 Sep 2019	17.000	28.000	66.667	116.667	55.440	71.225	53.909	11.600	12.450	4.444
31	20 Sep 2019	26.000	43.000	64.333	110.000	45.580	68.699	52.071	10.800	13.150	3.111

Table K-3c. Weighted sub-indices (Wn × qn). n = 31 samples.

No.	Date	Turb Wn:	pH 0.82199	TH 0.10275	TA 0.00274	TDS 0.00685	Ca <sup>2+</sup> 0.00164	Mg <sup>2+</sup> 0.01096	Cl <sup>-</sup> 0.02740	SO <sub>4</sub> <sup>2-</sup> 0.00329	NO <sub>3</sub> <sup>-</sup> 0.00411
1	15 Jan 2019	8.2199	2.5687	0.1644	0.8106	0.0809	0.7026	1.3294	0.0316	0.0594	0.0893
2	20 Jan 2019	16.4399	3.0825	0.1525	0.7992	0.0776	0.6518	1.2333	0.0334	0.0678	0.0852
3	25 Jan 2019	20.5498	2.2605	0.1553	0.8106	0.0784	0.6635	1.2555	0.0316	0.0820	0.0852
4	10 Feb 2019	16.4399	2.1577	0.1480	0.7992	0.0781	0.6323	1.1965	0.0316	0.0699	0.0771
5	20 Feb 2019	9.0419	4.1100	0.1553	0.8448	0.0976	0.6843	1.1768	0.0342	0.0596	0.0852
6	28 Feb 2019	8.2199	3.0825	0.1735	0.7877	0.1000	0.7377	1.4181	0.0302	0.0668	0.0649
7	10 Mar 2019	12.3299	2.5687	0.1772	0.7307	0.0809	0.7580	1.4296	0.0316	0.0616	0.0731
8	20 Mar 2019	24.6598	2.1577	0.1827	0.8677	0.0967	0.7806	1.4771	0.0355	0.0649	0.0649
9	31 Mar 2019	28.7698	2.3632	0.1516	0.7535	0.0831	0.6473	1.2285	0.0342	0.0664	0.0528
10	05 Apr 2019	24.6598	1.9522	0.1644	0.7535	0.0749	0.7026	1.3294	0.0302	0.0602	0.0731
11	15 Apr 2019	24.6598	2.1577	0.1681	0.7649	0.0739	0.7171	1.3629	0.0316	0.0649	0.0406
12	25 Apr 2019	24.6598	1.8495	0.1598	0.7421	0.0781	0.6827	1.2937	0.0342	0.0711	0.0649
13	30 Apr 2019	16.4399	2.1577	0.1644	0.7992	0.0854	0.7026	1.3294	0.0276	0.0625	0.0690
14	05 May 2019	13.9739	2.3632	0.1516	0.7135	0.0770	0.6473	1.2285	0.0302	0.0543	0.0649
15	05 May 2019	20.5498	1.7467	0.1480	0.7877	0.0767	0.6323	1.1965	0.0329	0.0526	0.0568
16	15 May 2019	24.6598	2.5687	0.1534	0.7535	0.0770	0.6567	1.2371	0.0342	0.0530	0.0568
17	25 May 2019	22.1938	2.5687	0.1553	0.6964	0.0693	0.6635	1.2555	0.0329	0.0596	0.0812
18	05 Jun 2019	9.8639	2.5687	0.1918	0.7649	0.0669	0.8786	1.3274	0.0355	0.0551	0.0690
19	10 Jun 2019	12.3299	2.1577	0.1936	0.7877	0.0664	0.8816	1.3606	0.0316	0.0551	0.0771
20	20 Jun 2019	16.4399	1.7467	0.1936	0.8106	0.0683	0.8816	1.3606	0.0316	0.0608	0.0812
21	30 Jun 2019	24.6598	3.2880	0.1918	0.7649	0.0714	0.8786	1.3274	0.0302	0.0629	0.0771
22	05 Jul 2019	13.1519	2.2605	0.1827	0.7706	0.0732	0.7806	1.4771	0.0329	0.0549	0.0649
23	15 Jul 2019	8.2199	3.0825	0.1863	0.7763	0.0725	0.7973	1.5026	0.0342	0.0565	0.0731
24	25 Jul 2019	8.2199	2.3632	0.1827	0.7535	0.0740	0.7806	1.4771	0.0342	0.0629	0.0609
25	31 Jul 2019	16.4399	1.8495	0.1772	0.7877	0.0657	0.7580	1.4296	0.0368	0.0590	0.0731
26	05 Aug 2019	20.5498	2.0550	0.2009	0.8106	0.0669	0.8608	1.6168	0.0355	0.0629	0.0690
27	15 Aug 2019	18.9058	2.5687	0.1735	0.9133	0.0739	0.7428	1.3986	0.0355	0.0616	0.0649
28	25 Aug 2019	17.2619	2.8770	0.1827	0.8562	0.0650	0.7806	1.4771	0.0316	0.0596	0.0771
29	01 Sep 2019	4.1100	3.2880	0.1735	0.8106	0.0657	0.7428	1.3986	0.0342	0.0538	0.0731
30	10 Sep 2019	13.9739	2.8770	0.1827	0.7992	0.0911	0.7806	1.4771	0.0381	0.0512	0.0812
31	20 Sep 2019	21.3718	4.4182	0.1763	0.7535	0.0749	0.7529	1.4267	0.0355	0.0540	0.0568

Table K-3d. Final WAWQI per sample and classification. Distribution: Excellent=19 (61%) Good=12 (39%) Poor=0 (0%) Very Poor=0 (0%)

No.	Date	WAWQI	Classification
	Ayoub (2017)	Mean=22.71±6.23	[10.75 – 34.15]
1	15 Jan 2019	14.06	Excellent
2	20 Jan 2019	22.62	Excellent
3	25 Jan 2019	25.97	Good
4	10 Feb 2019	21.63	Excellent
5	20 Feb 2019	16.29	Excellent
6	28 Feb 2019	14.68	Excellent

7	10 Mar 2019	18.24	Excellent
8	20 Mar 2019	30.39	Good
9	31 Mar 2019	34.15	Good
10	05 Apr 2019	29.80	Good
11	15 Apr 2019	30.04	Good
12	25 Apr 2019	29.64	Good
13	30 Apr 2019	21.84	Excellent
14	05 May 2019	19.30	Excellent
15	05 May 2019	25.28	Good
16	15 May 2019	30.25	Good
17	25 May 2019	27.78	Good
18	05 Jun 2019	15.82	Excellent
19	10 Jun 2019	17.94	Excellent
20	20 Jun 2019	21.67	Excellent
21	30 Jun 2019	31.35	Good
22	05 Jul 2019	18.85	Excellent
23	15 Jul 2019	14.80	Excellent
24	25 Jul 2019	14.01	Excellent
25	31 Jul 2019	21.68	Excellent
26	05 Aug 2019	26.33	Good
27	15 Aug 2019	24.94	Excellent
28	25 Aug 2019	23.67	Excellent
29	01 Sep 2019	10.75	Excellent
30	10 Sep 2019	20.35	Excellent
31	20 Sep 2019	29.12	Good

#### K-4 Comparative Calculation Summary

Table K-4 consolidates the final WAWQI for all 62 samples side-by-side, enabling direct visual comparison of pre- and post-upgrade water quality. The 65.6% improvement in integrated water quality (from 66.07 ± 19.36 to 22.71 ± 6.23) is demonstrated row-by-row.

Table K-4. Consolidated WAWQI — pre-upgrade (2018) vs post-upgrade (2019). Classification per Ayoub (2017).

No.	Pre Date	Pre WAWQI	Pre Class	Post Date	Post WAWQI	Post Class
Σ	Mean±SD	66.07±19.36	Good=7   Poor=11   VP=13	Mean±SD	22.71±6.23	Ex=19   Good=12
1	01 Jan 2018	74.37	Poor	15 Jan 2019	14.06	Excellent
2	15 Jan 2018	55.92	Poor	20 Jan 2019	22.62	Excellent
3	30 Jan 2018	54.98	Poor	25 Jan 2019	25.97	Good
4	10 Feb 2018	80.30	Very Poor	10 Feb 2019	21.63	Excellent
5	20 Feb 2018	47.18	Good	20 Feb 2019	16.29	Excellent
6	28 Feb 2018	36.84	Good	28 Feb 2019	14.68	Excellent
7	10 Mar 2018	52.04	Poor	10 Mar 2019	18.24	Excellent
8	20 Mar 2018	50.62	Poor	20 Mar 2019	30.39	Good
9	30 Mar 2018	65.01	Poor	31 Mar 2019	34.15	Good
10	10 Apr 2018	30.33	Good	05 Apr 2019	29.80	Good
11	20 Apr 2018	39.12	Good	15 Apr 2019	30.04	Good
12	30 Apr 2018	30.15	Good	25 Apr 2019	29.64	Good
13	10 May 2018	62.99	Poor	30 Apr 2019	21.84	Excellent
14	20 May 2018	80.44	Very Poor	05 May 2019	19.30	Excellent
15	30 May 2018	86.97	Very Poor	05 May 2019	25.28	Good
16	10 Jun 2018	71.98	Poor	15 May 2019	30.25	Good
17	20 Jun 2018	59.72	Poor	25 May 2019	27.78	Good
18	30 Jun 2018	47.09	Good	05 Jun 2019	15.82	Excellent
19	10 Jul 2018	79.26	Very Poor	10 Jun 2019	17.94	Excellent
20	20 Jul 2018	42.32	Good	20 Jun 2019	21.67	Excellent
21	30 Jul 2018	72.47	Poor	30 Jun 2019	31.35	Good
22	10 Aug 2018	75.74	Very Poor	05 Jul 2019	18.85	Excellent
23	20 Aug 2018	56.96	Poor	15 Jul 2019	14.80	Excellent
24	30 Aug 2018	87.51	Very Poor	25 Jul 2019	14.01	Excellent
25	10 Sep 2018	92.04	Very Poor	31 Jul 2019	21.68	Excellent
26	25 Sep 2018	76.49	Very Poor	05 Aug 2019	26.33	Good
27	10 Oct 2018	77.71	Very Poor	15 Aug 2019	24.94	Excellent
28	25 Oct 2018	90.49	Very Poor	25 Aug 2019	23.67	Excellent
29	10 Nov 2018	90.59	Very Poor	01 Sep 2019	10.75	Excellent
30	25 Nov 2018	89.42	Very Poor	10 Sep 2019	20.35	Excellent
31	04 Dec 2018	90.52	Very Poor	20 Sep 2019	29.12	Good

## K-5 Sensitivity Analysis — Parameter Contribution

Table K-5 shows the mean contribution of each parameter to the overall WAWQI in both periods, identifying dominant parameters.

Table K-5. Mean parameter contributions ( $W_n \times q_n$ ) to WAWQI — pre vs post.

#	Parameter	Pre Mean $W_n \times q_n$	Post Mean $W_n \times q_n$	$\Delta$	% of Pre WAWQI
1	Turb	59.2896	16.8376	-42.4520	89.8%
2	pH	2.8935	2.5522	-0.3414	4.4%
3	TH	0.1876	0.1714	-0.0161	0.3%
4	TA	0.9039	0.7863	-0.1177	1.4%
5	TDS	0.1016	0.0768	-0.0248	0.2%
6	Ca <sup>2+</sup>	0.7656	0.7407	-0.0250	1.2%
7	Mg <sup>2+</sup>	1.6648	1.3560	-0.3088	2.5%
8	Cl <sup>-</sup>	0.0476	0.0331	-0.0146	0.1%
9	SO <sub>4</sub> <sup>2-</sup>	0.0829	0.0609	-0.0220	0.1%
10	NO <sub>3</sub> <sup>-</sup>	0.1021	0.0704	-0.0316	0.2%
<b>Σ</b>	<b>WAWQI Total</b>	<b>66.07</b>	<b>22.71</b>	<b>-43.35 (65.6% ↓)</b>	<b>100.0%</b>

Post-Upgrade Treated Water — Jan to Sep 2019 (n = 31)

● Blue = lab input | ● Black = formula | Cols J,K: Ca<sup>2</sup> /Mg<sup>2</sup> derived by formula from CaH/MgH

No.	Date	Turbidity	pH	Total Hardness	Total Alk.	TDS	CaH <sup>3</sup> (CaCO )	MgH <sup>3</sup> (CaCO )	Ca <sup>2</sup> =formula	Mg <sup>2</sup> =formula	Cl	SO <sup>2</sup>	NO
		NTU	—	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Sn	WHO	1	8	300	120	500	—	—	75	30	250	200	45
1	15-Jan-19	0,100	7,250	180,000	142,000	245,900	120,060	59,940	48,077	14,555	24,000	28,900	2,200
2	20-Jan-19	0,200	7,300	167,000	140,000	235,900	111,389	55,611	44,605	13,504	25,400	33,000	2,100
3	25-Jan-19	0,250	7,220	170,000	142,000	238,500	113,390	56,610	45,406	13,747	24,000	39,900	2,100
4	10-Feb-19	0,200	7,210	162,000	140,000	237,400	108,054	53,946	43,269	13,100	24,000	34,000	1,900
5	20-Feb-19	0,110	7,400	170,000	148,000	296,800	113,390	56,610	45,406	13,747	26,000	29,000	2,100
6	28-Feb-19	0,100	7,300	190,000	138,000	304,200	126,730	63,270	50,748	15,364	23,000	32,500	1,600
7	10-Mar-19	0,150	7,250	194,000	128,000	245,900	129,398	64,602	51,816	15,687	24,000	30,000	1,800
8	20-Mar-19	0,300	7,210	200,000	152,000	294,200	133,400	66,600	53,419	16,173	27,000	31,600	1,600
9	31-Mar-19	0,350	7,230	166,000	132,000	252,800	110,722	55,278	44,337	13,423	26,000	32,300	1,300
10	05-Apr-19	0,300	7,190	180,000	132,000	227,900	120,060	59,940	48,077	14,555	23,000	29,300	1,800
11	15-Apr-19	0,300	7,210	184,000	134,000	224,700	122,728	61,272	49,145	14,879	24,000	31,600	1,000
12	25-Apr-19	0,300	7,180	175,000	130,000	237,400	116,725	58,275	46,741	14,151	26,000	34,600	1,600
13	30-Apr-19	0,200	7,210	180,000	140,000	259,700	120,060	59,940	48,077	14,555	21,000	30,400	1,700
14	05-May-19	0,170	7,230	166,000	125,000	234,300	110,722	55,278	44,337	13,423	23,000	26,400	1,600
15	05-May-19	0,250	7,170	162,000	138,000	233,200	108,054	53,946	43,269	13,100	25,000	25,600	1,400
16	15-May-19	0,300	7,250	168,000	132,000	234,300	112,056	55,944	44,872	13,585	26,000	25,800	1,400
17	25-May-19	0,270	7,250	170,000	122,000	210,900	113,390	56,610	45,406	13,747	25,000	29,000	2,000
18	05-Jun-19	0,120	7,250	210,000	134,000	203,500	140,070	69,930	56,090	16,981	27,000	26,800	1,700
19	10-Jun-19	0,150	7,210	212,000	138,000	201,900	141,404	70,596	56,624	17,143	24,000	26,800	1,900
20	20-Jun-19	0,200	7,170	212,000	142,000	207,800	141,404	70,596	56,624	17,143	24,000	29,600	2,000
21	30-Jun-19	0,300	7,320	210,000	134,000	217,300	140,070	69,930	56,090	16,981	23,000	30,600	1,900
22	05-Jul-19	0,160	7,220	200,000	135,000	222,600	133,400	66,600	53,419	16,173	25,000	26,700	1,600
23	15-Jul-19	0,100	7,300	204,000	136,000	220,500	136,068	67,932	54,487	16,496	26,000	27,500	1,800
24	25-Jul-19	0,100	7,230	200,000	132,000	225,200	133,400	66,600	53,419	16,173	26,000	30,600	1,500
25	31-Jul-19	0,200	7,180	194,000	138,000	199,800	129,398	64,602	51,816	15,687	28,000	28,700	1,800
26	05-Aug-19	0,250	7,200	220,000	142,000	203,500	146,740	73,260	58,761	17,790	27,000	30,600	1,700
27	15-Aug-19	0,230	7,250	190,000	160,000	224,700	126,730	63,270	50,748	15,364	27,000	30,000	1,600
28	25-Aug-19	0,210	7,280	200,000	150,000	197,700	133,400	66,600	53,419	16,173	24,000	29,000	1,900
29	01-Sep-19	0,050	7,320	190,000	142,000	199,800	126,730	63,270	50,748	15,364	26,000	26,200	1,800
30	10-Sep-19	0,170	7,280	200,000	140,000	277,200	133,400	66,600	53,419	16,173	29,000	24,900	2,000
31	20-Sep-19	0,260	7,430	193,000	132,000	227,900	128,731	64,269	51,549	15,607	27,000	26,300	1,400
<b>Mean</b>	<b>Summary</b>	<b>0,205</b>	<b>7,248</b>	<b>187,710</b>	<b>137,742</b>	<b>233,658</b>	<b>125,202</b>	<b>62,507</b>	<b>50,136</b>	<b>15,179</b>	<b>25,142</b>	<b>29,619</b>	<b>1,735</b>
<b>SD</b>	<b>Summary</b>	<b>0,078</b>	<b>0,062</b>	<b>17,065</b>	<b>7,848</b>	<b>28,512</b>	<b>11,382</b>	<b>5,683</b>	<b>4,558</b>	<b>1,380</b>	<b>1,747</b>	<b>3,193</b>	<b>0,270</b>
<b>Min</b>	<b>Summary</b>	<b>0,050</b>	<b>7,170</b>	<b>162,000</b>	<b>122,000</b>	<b>197,700</b>	<b>108,054</b>	<b>53,946</b>	<b>43,269</b>	<b>13,100</b>	<b>21,000</b>	<b>24,900</b>	<b>1,000</b>
<b>Max</b>	<b>Summary</b>	<b>0,350</b>	<b>7,430</b>	<b>220,000</b>	<b>160,000</b>	<b>304,200</b>	<b>146,740</b>	<b>73,260</b>	<b>58,761</b>	<b>17,790</b>	<b>29,000</b>	<b>39,900</b>	<b>2,200</b>

# STATISTICAL ANALYSIS WORKBOOK — EI-Galaa Water Treatment Plant | EEET-04501-2026-02

Method: Welch t-test (=T.TEST type=3) + Cohen's d | WQI: Ayoub (2017) | Microsoft Excel (Microsoft 365)

## COLOUR CODE

- BLUE text = Hardcoded lab measurement (raw input). Do not edit unless correcting source data.
- BLACK text = Computed by Excel formula. Click any cell to inspect the formula in the formula bar.
- GREEN text = Cross-sheet formula (references another sheet in this workbook).
- YELLOW background = WQI classification: Poor (51–75)
- RED background = WQI classification: Very Poor (76–100)
- CYAN background = WQI classification: Good (26–50)
- Green background = WQI classification: Excellent (0–25)

## SHEET STRUCTURE

- Sheet 1: README — Colour code, equations, methodology notes
- Sheet 2: Pre\_2018 — 31 pre-upgrade treated water samples (Jan–Dec 2018). Blue = lab inputs.
- Sheet 3: Post\_2019 — 31 post-upgrade treated water samples (Jan–Sep 2019). Same structure as Pre\_2018
- Sheet 4: WQI\_Params — WAWQI parameters. K = formula. Wn = K/Sn formula per parameter. Equations shown above table
- Sheet 5: WQI\_Calc —  $qn \times Wn$  sub-indices and WAWQI per sample. All formulas reference Pre\_2018/Post\_2019 + WQI\_Params
- Sheet 6: Stats\_Sum — AVERAGE/STDEV/MIN/MAX formulas referencing raw data sheets.
- Sheet 7: Welch\_t — T.TEST (pre,post,2,3) for p-value. T.INV for t-stat. Welch df by formula. Cohen's d hv formula
- Sheet 8: WQI\_Sum — COUNTIF classification counts. AVERAGE/STDEV from WQI\_Calc.

## WAWQI EQUATIONS (Ayoub, 2017)

$$\text{Eq. 1: } \text{WAWQI} = \sum [Wn \times qn]$$

$$\text{Eq. 2: } qn = [(Vn - Vid) / (Sn - Vid)] \times 100$$

$$\text{Eq. 3: } Wn = K / Sn$$

$$\text{Eq. 4: } K = 1 / \sum(1/Sn) = 0.821993 \rightarrow \sum Wn = 1.000000$$

Where: Vn = measured concentration | Vid = ideal value (= 0 except pH where Vid = 7.0) | Sn = WHO (2011) standard

## Ca<sup>2</sup> / Mg<sup>2</sup> DERIVATION

Lab measures CaH (Calcium Hardness) and MgH (Magnesium Hardness) in mg/L as CaCO<sub>3</sub>, not as free ions

$$\text{Ca}^2 \text{ (mg/L)} = \text{CaH} \times (40.08 / 100.09) \leftarrow \text{formula in column J of Pre\_2018 and Post\_2019}$$

$$\text{Mg}^2 \text{ (mg/L)} = \text{MgH} \times (24.305 / 100.09) \leftarrow \text{formula in column K of Pre\_2018 and Post\_2019}$$

WHO Sn: Ca<sup>2</sup> = 75 mg/L | Mg<sup>2</sup> = 30 mg/L (ionic concentrations per Ayoub 2017 / WHO 2011)

## Mn (MANGANESE)

Pre-2018: Mn = 0.000 mg/L in all 31 samples — below detection limit (< 0.001 mg/L). NOT included in WAWQI

Post-2019: Mn = ND (not detected) in all 31 samples. NOT included in WAWQI.

**Pre-Upgrade Treated Water — Jan to Dec 2018 (n = 31)**

● Blue = lab input | ● Black = formula | Cols J,K: Ca<sup>2</sup> /Mg<sup>2</sup> derived by formula from CaH/MgH

No.	Date	Turbidity	pH	Total Hardness	Total Alk.	TDS	CaH <sup>3</sup> (CaCO <sub>3</sub> )	MgH <sup>3</sup> (CaCO <sub>3</sub> )	Ca <sup>2</sup> =formula	Mg <sup>2</sup> =formula	Cl	SO <sup>2</sup>	NO
		NTU	—	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
<b>Sn</b>	<b>WHO</b>	<b>1</b>	<b>8</b>	<b>300</b>	<b>120</b>	<b>500</b>	<b>—</b>	<b>—</b>	<b>75</b>	<b>30</b>	<b>250</b>	<b>200</b>	<b>45</b>
1	01-Jan-18	0,820	7,290	208,000	166,000	361,000	130,000	78,000	52,057	18,941	42,000	43,600	2,350
2	15-Jan-18	0,600	7,220	216,000	166,000	357,000	120,000	96,000	48,053	23,312	47,000	46,000	2,200
3	30-Jan-18	0,590	7,220	216,000	162,000	382,000	126,000	90,000	50,455	21,855	39,000	42,000	2,500
4	10-Feb-18	0,900	7,210	208,000	172,000	329,000	120,000	88,000	48,053	21,369	37,000	40,000	2,500
5	20-Feb-18	0,500	7,240	192,000	152,000	272,000	122,000	70,000	48,854	16,998	39,000	43,300	2,600
6	28-Feb-18	0,370	7,220	216,000	164,000	345,000	150,000	66,000	60,066	16,027	42,000	43,500	2,700
7	10-Mar-18	0,550	7,250	230,000	160,000	293,000	140,000	90,000	56,062	21,855	46,000	48,000	2,400
8	20-Mar-18	0,540	7,210	216,000	158,000	306,000	146,000	70,000	58,464	16,998	45,000	49,000	3,600
9	30-Mar-18	0,720	7,160	230,000	164,000	304,000	148,000	82,000	59,265	19,912	44,000	44,200	2,600
10	10-Apr-18	0,300	7,190	200,000	156,000	305,000	120,000	80,000	48,053	19,427	37,000	42,600	2,400
11	20-Apr-18	0,400	7,210	226,000	164,000	327,000	146,000	80,000	58,464	19,427	41,000	40,500	2,500
12	30-Apr-18	0,300	7,180	194,000	154,000	300,000	124,000	70,000	49,655	16,998	28,000	34,600	2,400
13	10-May-18	0,690	7,210	216,000	168,000	312,000	120,000	96,000	48,053	23,312	34,000	30,400	2,100
14	20-May-18	0,900	7,230	224,000	152,000	330,000	140,000	84,000	56,062	20,398	40,000	42,000	2,400
15	30-May-18	1,000	7,170	170,000	140,000	235,000	120,000	50,000	48,053	12,142	25,000	26,400	2,400
16	10-Jun-18	0,800	7,250	196,000	144,000	300,000	126,000	70,000	50,455	16,998	37,000	43,800	2,200
17	20-Jun-18	0,650	7,250	200,000	136,000	274,000	130,000	70,000	52,057	16,998	27,000	40,600	2,000
18	30-Jun-18	0,500	7,250	182,000	160,000	288,000	126,000	56,000	50,455	13,599	27,000	29,000	1,900
19	10-Jul-18	0,900	7,210	160,000	145,000	248,000	100,000	60,000	40,044	14,570	24,000	26,800	4,000
20	20-Jul-18	0,450	7,170	194,000	160,000	290,000	134,000	60,000	53,659	14,570	35,000	39,200	3,000
21	30-Jul-18	0,800	7,320	174,000	160,000	277,000	110,000	64,000	44,048	15,541	40,000	34,600	2,700
22	10-Aug-18	0,850	7,220	190,000	148,000	285,000	116,000	74,000	46,451	17,970	34,000	43,000	2,600
23	20-Aug-18	0,600	7,360	214,000	160,000	310,000	140,000	74,000	56,062	17,970	31,000	36,200	2,100
24	30-Aug-18	0,950	7,550	202,000	160,000	296,000	122,000	80,000	48,854	19,427	34,000	34,200	2,600
25	10-Sep-18	1,000	7,540	218,000	172,000	328,000	126,000	92,000	50,455	22,340	34,000	44,500	2,200
26	25-Sep-18	0,830	7,400	225,000	172,000	313,000	135,000	90,000	54,059	21,855	32,000	46,600	2,900
27	10-Oct-18	0,850	7,410	184,000	148,000	302,000	120,000	84,000	48,053	20,398	32,000	43,000	2,300
28	25-Oct-18	1,000	7,410	220,000	166,000	333,000	140,000	80,000	56,062	19,427	34,000	40,600	2,400
29	10-Nov-18	1,000	7,430	210,000	162,000	341,000	130,000	80,000	52,057	19,427	38,000	44,900	2,400
30	25-Nov-18	1,000	7,320	220,000	162,000	325,000	150,000	70,000	60,066	16,998	39,000	41,600	2,500
31	04-Dec-18	1,000	7,430	216,000	156,000	314,000	130,000	86,000	52,057	20,884	39,000	46,000	2,500
<b>Mean Summary</b>		<b>0,721</b>	<b>7,282</b>	<b>205,387</b>	<b>158,355</b>	<b>309,097</b>	<b>129,258</b>	<b>76,774</b>	<b>51,760</b>	<b>18,643</b>	<b>36,226</b>	<b>40,345</b>	<b>2,515</b>
<b>SD Summary</b>		<b>0,227</b>	<b>0,107</b>	<b>18,141</b>	<b>9,174</b>	<b>31,594</b>	<b>12,088</b>	<b>11,795</b>	<b>4,841</b>	<b>2,864</b>	<b>6,070</b>	<b>6,014</b>	<b>0,421</b>
<b>Min Summary</b>		<b>0,300</b>	<b>7,160</b>	<b>160,000</b>	<b>136,000</b>	<b>235,000</b>	<b>100,000</b>	<b>50,000</b>	<b>40,044</b>	<b>12,142</b>	<b>24,000</b>	<b>26,400</b>	<b>1,900</b>
<b>Max Summary</b>		<b>1,000</b>	<b>7,550</b>	<b>230,000</b>	<b>172,000</b>	<b>382,000</b>	<b>150,000</b>	<b>96,000</b>	<b>60,066</b>	<b>23,312</b>	<b>47,000</b>	<b>49,000</b>	<b>4,000</b>

**WAWQI Methodology — Ayoub (2017) |  $K = 1/\Sigma(1/S_n) = 0.821993$  |  $\Sigma W_n = 1.000$**

**KEY EQUATIONS**

**Eq. 1:  $WAWQI = \Sigma [ W_n \times q_n ]$**

Eq. 2:  $q_n = [ (V_n - Vid) / (S_n - Vid) ] \times 100$

Eq. 3:  $W_n = K / S_n$

Eq. 4:  $K = 1 / \Sigma(1/S_n) = 0.821993 \rightarrow \Sigma W_n = 1.000000$

Where:  $V_n$  = measured value |  $Vid$  = ideal value |  $S_n$  = WHO (2011) standard |  $Vid = 0$  except pH ( $Vid = 7.0$ )

**$K = 1/\Sigma(1/S_n)$  (auto-computed) → **0,821993** ← K constant. All  $W_n$  values reference this cell.**

**Table K-1. WAWQI Parameter Weights (Sn = WHO 2011 Standards)**

#	Parameter	Unit	Sn (WHO 2011)	Vid	K (ref cell D10)	Wn = K/Sn	Wn × 1000
1	Turbidity	NTU	1	0	0,821993	<b>0,821993</b>	821,993
2	pH	—	8	7	0,821993	<b>0,102749</b>	102,749
3	Total Hardness	mg/L	300	0	0,821993	<b>0,002740</b>	2,740
4	Total Alkalinity	mg/L	120	0	0,821993	<b>0,006850</b>	6,850
5	TDS	mg/L	500	0	0,821993	<b>0,001644</b>	1,644
6	<b>Ca<sup>2</sup></b>	mg/L	75	0	0,821993	<b>0,010960</b>	10,960
7	<b>Mg<sup>2</sup></b>	mg/L	30	0	0,821993	<b>0,027400</b>	27,400
8	Cl	mg/L	250	0	0,821993	<b>0,003288</b>	3,288
9	SO <sup>2</sup>	mg/L	200	0	0,821993	<b>0,004110</b>	4,110
10	NO	mg/L	45	0	0,821993	<b>0,018267</b>	18,267
<b><math>\Sigma(1/S_n) = 1.216556</math>   <math>K = 0.821993</math>   <math>\Sigma W_n = \rightarrow</math></b>						<b>1,000000</b>	<b>→ Must = 1.000000</b>
<b>⚠ Ca<sup>2</sup> and Mg<sup>2</sup> are not measured directly — derived from CaH/MgH: Ca<sup>2</sup> =CaH×(40.08/100.09); Mg<sup>2</sup> =MgH×(24.305/100.09). See columns J,K in Pre_2018 / Post_2019.</b>							

**WQI Classification Scale — Ayoub (2017)**

WQI Range	Classification	Colour
0–25	<b>Excellent</b>	#00B050
26–50	<b>Good</b>	#00B0F0
51–75	<b>Poor</b>	#FFC000
76–100	<b>Very Poor</b>	#FF0000
>100	<b>Unsuitable</b>	#C00000

### WAWQI Calculation — Pre-Upgrade 2018 (n=31)

Each cell (cols C–L) =  $W_n \times q_n$  | WAWQI (col M) =  $\Sigma(W_n \times q_n)$  | Class (col N) = IF formula | Green = cross-sheet formula

No.	Date	Turbidity	pH	Total Hardness	Total Alkalinity	TDS	Ca <sup>2</sup>	Mg <sup>2</sup>	Cl	SO <sup>2</sup>	NO	WAWQI	Class
1	01-Jan-18	67,403	2,980	0,190	0,948	0,119	0,761	1,730	0,055	0,090	0,095	74,37	Poor
2	15-Jan-18	49,320	2,260	0,197	0,948	0,117	0,702	2,129	0,062	0,095	0,089	55,92	Poor
3	30-Jan-18	48,498	2,260	0,197	0,925	0,126	0,737	1,996	0,051	0,086	0,101	54,98	Poor
4	10-Feb-18	73,979	2,158	0,190	0,982	0,108	0,702	1,952	0,049	0,082	0,101	80,30	Very Poor
5	20-Feb-18	41,100	2,466	0,175	0,868	0,089	0,714	1,552	0,051	0,089	0,106	47,21	Good
6	28-Feb-18	30,414	2,260	0,197	0,936	0,113	0,878	1,464	0,055	0,089	0,110	36,52	Good
7	10-Mar-18	45,210	2,569	0,210	0,913	0,096	0,819	1,996	0,060	0,099	0,097	52,07	Poor
8	20-Mar-18	44,388	2,158	0,197	0,902	0,101	0,854	1,552	0,059	0,101	0,146	50,46	Poor
9	30-Mar-18	59,183	1,644	0,210	0,936	0,100	0,866	1,819	0,058	0,091	0,106	65,01	Poor
10	10-Apr-18	24,660	1,952	0,183	0,890	0,100	0,702	1,774	0,049	0,088	0,097	30,50	Good
11	20-Apr-18	32,880	2,158	0,206	0,936	0,108	0,854	1,774	0,054	0,083	0,101	39,15	Good
12	30-Apr-18	24,660	1,849	0,177	0,879	0,099	0,726	1,552	0,037	0,071	0,097	30,15	Good
13	10-May-18	56,718	2,158	0,197	0,959	0,103	0,702	2,129	0,045	0,062	0,085	63,16	Poor
14	20-May-18	73,979	2,363	0,205	0,868	0,109	0,819	1,863	0,053	0,086	0,097	80,44	Very Poor
15	30-May-18	82,199	1,747	0,155	0,799	0,077	0,702	1,109	0,033	0,054	0,097	86,97	Very Poor
16	10-Jun-18	65,759	2,569	0,179	0,822	0,099	0,737	1,552	0,049	0,090	0,089	71,95	Poor
17	20-Jun-18	53,430	2,569	0,183	0,776	0,090	0,761	1,552	0,036	0,083	0,081	59,56	Poor
18	30-Jun-18	41,100	2,569	0,166	0,913	0,095	0,737	1,242	0,036	0,060	0,077	46,99	Good
19	10-Jul-18	73,979	2,158	0,146	0,828	0,082	0,585	1,331	0,032	0,055	0,162	79,36	Very Poor
20	20-Jul-18	36,990	1,747	0,177	0,913	0,095	0,784	1,331	0,046	0,081	0,122	42,29	Good
21	30-Jul-18	65,759	3,288	0,159	0,913	0,091	0,644	1,419	0,053	0,071	0,110	72,51	Poor
22	10-Aug-18	69,869	2,260	0,174	0,845	0,094	0,679	1,641	0,045	0,088	0,106	75,80	Very Poor
23	20-Aug-18	49,320	3,699	0,195	0,913	0,102	0,819	1,641	0,041	0,074	0,085	56,89	Poor
24	30-Aug-18	78,089	5,651	0,184	0,913	0,097	0,714	1,774	0,045	0,070	0,106	87,64	Very Poor
25	10-Sep-18	82,199	5,548	0,199	0,982	0,108	0,737	2,040	0,045	0,091	0,089	92,04	Very Poor
26	25-Sep-18	68,225	4,110	0,205	0,982	0,103	0,790	1,996	0,042	0,096	0,118	76,67	Very Poor
27	10-Oct-18	69,869	4,213	0,168	0,845	0,099	0,702	1,863	0,042	0,088	0,093	77,98	Very Poor
28	25-Oct-18	82,199	4,213	0,201	0,948	0,109	0,819	1,774	0,045	0,083	0,097	90,49	Very Poor
29	10-Nov-18	82,199	4,418	0,192	0,925	0,112	0,761	1,774	0,050	0,092	0,097	90,62	Very Poor
30	25-Nov-18	82,199	3,288	0,201	0,925	0,107	0,878	1,552	0,051	0,085	0,101	89,39	Very Poor
31	04-Dec-18	82,199	4,418	0,197	0,890	0,103	0,761	1,907	0,051	0,095	0,101	90,72	Very Poor

### WAWQI Calculation — Post-Upgrade 2019 (n=31)

Each cell (cols C–L) =  $W_n \times q_n$  | WAWQI (col M) =  $\Sigma(W_n \times q_n)$  | Class (col N) = IF formula | Green = cross-sheet formula

No.	Date	Turbidity	pH	Total Hardness	Total Alkalinity	TDS	Ca <sup>2</sup>	Mg <sup>2</sup>	Cl	SO <sup>2</sup>	NO	WAWQI	Class
1	15-Jan-19	8,220	2,569	0,164	0,811	0,081	0,703	1,329	0,032	0,059	0,089	14,06	Excellent
2	20-Jan-19	16,440	3,082	0,153	0,799	0,078	0,652	1,233	0,033	0,068	0,085	22,62	Excellent
3	25-Jan-19	20,550	2,260	0,155	0,811	0,078	0,664	1,256	0,032	0,082	0,085	25,97	Good
4	10-Feb-19	16,440	2,158	0,148	0,799	0,078	0,632	1,196	0,032	0,070	0,077	21,63	Excellent
5	20-Feb-19	9,042	4,110	0,155	0,845	0,098	0,664	1,256	0,034	0,060	0,085	16,35	Excellent
6	28-Feb-19	8,220	3,082	0,174	0,788	0,100	0,742	1,403	0,030	0,067	0,065	14,67	Excellent
7	10-Mar-19	12,330	2,569	0,177	0,731	0,081	0,757	1,433	0,032	0,062	0,073	18,24	Excellent
8	20-Mar-19	24,660	2,158	0,183	0,868	0,097	0,781	1,477	0,036	0,065	0,065	30,39	Good
9	31-Mar-19	28,770	2,363	0,152	0,753	0,083	0,648	1,226	0,034	0,066	0,053	34,15	Good
10	05-Apr-19	24,660	1,952	0,164	0,753	0,075	0,703	1,329	0,030	0,060	0,073	29,80	Good
11	15-Apr-19	24,660	2,158	0,168	0,765	0,074	0,718	1,359	0,032	0,065	0,041	30,04	Good
12	25-Apr-19	24,660	1,849	0,160	0,742	0,078	0,683	1,292	0,034	0,071	0,065	29,63	Good
13	30-Apr-19	16,440	2,158	0,164	0,799	0,085	0,703	1,329	0,028	0,062	0,069	21,84	Excellent
14	05-May-19	13,974	2,363	0,152	0,714	0,077	0,648	1,226	0,030	0,054	0,065	19,30	Excellent
15	05-May-19	20,550	1,747	0,148	0,788	0,077	0,632	1,196	0,033	0,053	0,057	25,28	Good
16	15-May-19	24,660	2,569	0,153	0,753	0,077	0,656	1,241	0,034	0,053	0,057	30,25	Good
17	25-May-19	22,194	2,569	0,155	0,696	0,069	0,664	1,256	0,033	0,060	0,081	27,78	Good
18	05-Jun-19	9,864	2,569	0,192	0,765	0,067	0,820	1,551	0,036	0,055	0,069	15,99	Excellent
19	10-Jun-19	12,330	2,158	0,194	0,788	0,066	0,827	1,566	0,032	0,055	0,077	18,09	Excellent
20	20-Jun-19	16,440	1,747	0,194	0,811	0,068	0,827	1,566	0,032	0,061	0,081	21,83	Excellent
21	30-Jun-19	24,660	3,288	0,192	0,765	0,071	0,820	1,551	0,030	0,063	0,077	31,52	Good
22	05-Jul-19	13,152	2,260	0,183	0,771	0,073	0,781	1,477	0,033	0,055	0,065	18,85	Excellent
23	15-Jul-19	8,220	3,082	0,186	0,776	0,072	0,796	1,507	0,034	0,057	0,073	14,80	Excellent
24	25-Jul-19	8,220	2,363	0,183	0,753	0,074	0,781	1,477	0,034	0,063	0,061	14,01	Excellent
25	31-Jul-19	16,440	1,849	0,177	0,788	0,066	0,757	1,433	0,037	0,059	0,073	21,68	Excellent
26	05-Aug-19	20,550	2,055	0,201	0,811	0,067	0,859	1,625	0,036	0,063	0,069	26,33	Good
27	15-Aug-19	18,906	2,569	0,174	0,913	0,074	0,742	1,403	0,036	0,062	0,065	24,94	Excellent

28	25-Aug-19	17,262	2,877	0,183	0,856	0,065	0,781	1,477	0,032	0,060	0,077	<b>23,67</b>	<b>Excellent</b>
29	01-Sep-19	4,110	3,288	0,174	0,811	0,066	0,742	1,403	0,034	0,054	0,073	<b>10,75</b>	<b>Excellent</b>
30	10-Sep-19	13,974	2,877	0,183	0,799	0,091	0,781	1,477	0,038	0,051	0,081	<b>20,35</b>	<b>Excellent</b>
31	20-Sep-19	21,372	4,418	0,176	0,753	0,075	0,753	1,425	0,036	0,054	0,057	<b>29,12</b>	<b>Good</b>

**Descriptive Statistics — Pre-upgrade 2018 vs Post-upgrade 2019**

Parameter	Unit	Pre-upgrade 2018				Post-upgrade 2019				Δ	% Δ
		Pre Mean	Pre SD	Pre Min	Pre Max	Post Mean	Post SD	Post Min	Post Max		
Turbidity	NTU	0,721	0,227	0,300	1,000	0,205	0,078	0,050	0,350	<b>-0,516</b>	<b>-71,6</b>
pH	—	7,282	0,107	7,160	7,550	7,248	0,062	7,170	7,430	<b>-0,033</b>	<b>-0,5</b>
Total Hardness	mg/L	205,387	18,141	160,000	230,000	187,710	17,065	162,000	220,000	<b>-17,677</b>	<b>-8,6</b>
Total Alkalinity	mg/L	158,355	9,174	136,000	172,000	137,742	7,848	122,000	160,000	<b>-20,613</b>	<b>-13,0</b>
TDS	mg/L	309,097	31,594	235,000	382,000	233,658	28,512	197,700	304,200	<b>-75,439</b>	<b>-24,4</b>
Ca <sup>2</sup> (ion)	mg/L	51,760	4,841	40,044	60,066	50,136	4,558	43,269	58,761	<b>-1,624</b>	<b>-3,1</b>
Mg <sup>2</sup> (ion)	mg/L	18,643	2,864	12,142	23,312	15,179	1,380	13,100	17,790	<b>-3,464</b>	<b>-18,6</b>
Cl	mg/L	36,226	6,070	24,000	47,000	25,142	1,747	21,000	29,000	<b>-11,084</b>	<b>-30,6</b>
SO <sup>2</sup>	mg/L	40,345	6,014	26,400	49,000	29,619	3,193	24,900	39,900	<b>-10,726</b>	<b>-26,6</b>
NO	mg/L	2,515	0,421	1,900	4,000	1,735	0,270	1,000	2,200	<b>-0,779</b>	<b>-31,0</b>
WAWQI	—	66,068	19,363	30,148	92,040	22,708	6,225	10,754	34,148	<b>-43,360</b>	<b>-65,6</b>

**Welch t-Test | p-value = TTEST(pre,post,2,3) | df = Welch-Satterthwaite formula |  $\alpha = 0.05$**

Type = 3 (Welch, unequal variance). t-stat = TINV(p, df). Cohen's d = pooled SD formula.

Parameter	Unit	Pre Mean	Pre SD	Post Mean	Post SD	p-value =TTEST()	df (formula)	t-stat =TINV()	Significance	Cohen's d (formula)
Turbidity	NTU	0,721	0,227	0,205	0,078	0,0000	37,0	11,967	p < 0.001 ***	3,038
pH	—	7,282	0,107	7,248	0,062	0,1419	47,8	1,494	NS	0,379
Total Hardness	mg/L	205,387	18,141	187,710	17,065	0,0002	59,8	3,955	p < 0.001 ***	1,004
Total Alkalinity	mg/L	158,355	9,174	137,742	7,848	0,0000	58,6	9,533	p < 0.001 ***	2,414
TDS	mg/L	309,097	31,594	233,658	28,512	0,0000	59,4	9,888	p < 0.001 ***	2,507
Ca <sup>2</sup> (ion)	mg/L	51,760	4,841	50,136	4,558	0,1789	59,8	1,360	NS	0,345
Mg <sup>2</sup> (ion)	mg/L	18,643	2,864	15,179	1,380	0,0000	43,2	6,073	p < 0.001 ***	1,541
Cl	mg/L	36,226	6,070	25,142	1,747	0,0000	34,9	9,881	p < 0.001 ***	2,482
SO <sup>2</sup>	mg/L	40,345	6,014	29,619	3,193	0,0000	45,7	8,809	p < 0.001 ***	2,228
NO	mg/L	2,515	0,421	1,735	0,270	0,0000	51,1	8,677	p < 0.001 ***	2,202
WAWQI	—	66,068	19,363	22,708	6,225	0,0000	36,1	11,893	p < 0.001 ***	3,015

**Cohen's d interpretation: Small > 0.20 | Medium > 0.50 | Large > 0.80**

**WAWQI Summary — All values computed by COUNTIF / AVERAGE / STDEV formulas**

Metric	Pre-2018	Post-2019	Δ (Post-Pre)	% Change	Significance	Classification Shift
WAWQI Mean	66,07	22,71	-43,36	-65,6	p<0.001 ***	Poor → Excellent
WAWQI SD	19,36	6,23	-13,14	-67,8	—	More consistent
WAWQI Min	30,15	10,75	-19,39	-64,3	—	—
WAWQI Max	92,04	34,15	-57,89	-62,9	—	—
n Excellent (WQI ≤ 25)	0	19	+19	0,0	—	0% → 61%
n Good (26 – 50)	7	12	+5	+71,4	—	23% → 39%
n Poor (51 – 75)	11	0	-11	-100,0	—	35% → 0%
n Very Poor (76 – 100)	13	0	-13	-100,0	—	42% → 0%
n Unsuitable (> 100)	0	0	0	0,0	—	0% → 0%