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PERFORMANCE EVALUATION OF A CONVENTIONAL DRINKING-WATER TREATMENT PLANT: A 12-MONTH CASE STUDY OF THE AL- DHULUIYA WATER PROJECT, SALAH AL-DIN, IRAQ

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Abstract

The Al-Dhuluiya conventional water treatment plant (WTP), in Salah Al-Din Governorate, Iraq, receives raw water from the Tigris River, and this paper presents the results of a 12-month (2024-2025) physicochemical study of the plant. Paired grab samples were taken once a month at the plant inlet (before coagulation) and at the final outlet (after chlorination) through a full hydrological year (November–October) and analysed for twelve parameters including colour, turbidity, pH, total dissolved solids (TDS), total hardness (as CaCO_3), sulfate, nitrite, chloride, nitrate, calcium, magnesium and free residual chlorine. Removal percentage was determined for each parameter and paired samples t-tests were used to identify if differences between the influent and effluent were statistically different. A weighted arithmetic water quality index (WAWQI) was calculated for each month's sample at all sampling sites and compared with four standard norms: Iraqi standard (IQS 417), WHO (2017), US EPA drinking water (2017), and EU Directive (2020/2184). The overall average turbidity removal was 92.8 per cent (inlet turbidity: 31.8 ± 32.1 NTU; outlet turbidity: 2.3 ± 1.3 NTU); and all nine chemical parameters were reduced statistically significantly ($p < 0.05$). At the inlet, the median WAWQI was 158.4 ("Unsuitable"), while it was 23.2 ("Good")

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at the outlet; and none of the effluent samples exceeded the IQS 417 or WHO limits. A few months reached a marginal exceedance of the operational turbidity limit set by US EPA/EU of 1 NTU, but the recorded turbidity values were all below the Iraqi/WHO limit of 5 NTU.

Keywords: drinking water treatment; performance evaluation; removal efficiency; WAWQI; Tigris River; Iraq

Highlights

- A complete hydrological year of paired monthly samples ($n = 12$) was used to evaluate a conventional surface-water WTP on the Tigris River.
- The mean turbidity removal was 92.8%, which means that the peak turbidity level of the season (125 NTU) dropped to 3.5 NTU in April while the effluent limit was not exceeded.
- The inlet–outlet reductions were statistically significant for all nine chemical parameters (when using paired t-tests).
- The WAWQI has been enhanced from a median of 158.4 ("Unsuitable") at the inlet to 23.2 ("Good") at the outlet over all twelve months.
- On every parameter effluent met IQS 417 and WHO limits; five months exceeded the stricter US EPA/EU operational limit of 1 NTU for turbidity.

1. Introduction

Much of central Iraq's drinking water from conventional surface-water treatment plants (SWTP) from the Tigris River and its tributaries. These plants generally use the sequentially proven combination of aluminium-sulfate coagulation, flocculation, lamella or horizontal sedimentation, rapid sand filtration and final chlorination—a combination that has been essentially unchanged for decades. With proper maintenance and operation, the train can extract water of international and national standards even from the most variable river Tigris.

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Whether it does or does not at any particular plant, however, is a question that cannot be answered without data from the systematic monitoring.

The Al-Dhuluiya WTP is located in Al-Dhuluiya town and its neighboring districts in Salah Al-Din Governorate. The Tigris is a river that experiences substantial seasonal variations in discharge, turbidity, and dissolved-load chemistry due to snowmelt from the headwaters in Turkey and Iran, as well as rainfall during spring and fluctuating amounts of upstream agricultural and municipal loadings [12]. Notwithstanding, there has not been a thorough multi-parameter, statistically sound evaluation of this plant published. The performance information that is available from most WTPs in Iraqi literature is limited to turbidity data only or limited to a single season or limited to relatively larger WTPs in Baghdad or in Basra [10,12].

The present study fills that gap. Twelve physicochemical parameters were monitored monthly over a full year at paired inlet and outlet sampling points, producing 12 paired observations per parameter — enough to support parametric statistical testing across all four seasons. Beyond removal-efficiency calculation, paired t-tests were used to separate genuine treatment effects from sampling noise, Pearson correlations were computed to interpret the hydrochemical structure of the raw water, and a WAWQI was applied to reduce the twelve individual results to a single, internationally recognised quality score for each monthly sample. Effluent quality was then compared against IQS 417 [7], WHO [4], US EPA [5], and EU [6] standards simultaneously, rather than against a single reference, which is the approach now expected in many Scopus-indexed water-quality journals.

2. Literature Review

Coagulation–flocculation–sedimentation–filtration is broadly acknowledged as the most cost-effective option for removing turbidity and particulate-associated contaminants from surface water, and performance data from plants across the

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Middle East confirm that well-operated conventional trains routinely achieve turbidity removals above 90% even during high-flow periods [8,9]. Iraqi research has largely the same picture. In fact, Khlaif et al. [10] reported that the Al-Muthanna plant had poor effluent quality during high increase in the inlet turbidity, which was caused by insufficient dosing of the coagulant and not by the process itself. Turbidity removal above 90% was obtained in bench scale tests by Shihab and Ahmad [11] using the tube settlers and they attributed this to the increase in the particle contact time during slow settling phase. Al-Musawi et al. [12] examined a broader scale and determined that seasonal flow regime, rather than point-source pollution, was the most important factor influencing water-quality variability in the Tigris at Baghdad, a likely conclusion of which also applies to a site upstream, such as Al-Dhuluiya.

The situation is not as rosy for other parameters like TDS, hardness, and sulfate. No particulate material in these species is not dissolved and will not be removed by sedimentation or filtration. It is usually thought that any reduction in a conventional WTP effluent is due to incidental co-precipitation of some ionic material with the coagulant floc, or that it is due to dilution at high flow conditions, but not that it is due to a specifically designed mechanism for removal [8,9].

Water quality indices are able to reduce multi-parameter datasets to a format that is easily understood by regulators, the public and plant operators that are not immediately comfortable interpreting tables of individual chemical concentrations. The first widely used WQI was introduced by Horton [1] in 1965, and was later modified by Brown et al. [2] to produce the WAWQI, in which the unit weights are inversely proportional to the permissible standard value for each parameter. It gives more weight to turbidity under the scheme of IQS 417, where the permissible limit is very low and hence exceeding the permissible limit in the above scheme is proportionately high. The WAWQI has been applied in a range

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of Iraqi water-quality studies, and Uddin et al. [3] provide a recent critical review of its strengths and limitations relative to more complex multivariate approaches.

3. Materials and Methods

3.1 Study Area and Treatment Process

The Al-Dhuluiya WTP is a medium-sized conventional plant located on the west bank of the Tigris at Al-Dhuluiya town, Salah Al-Din Governorate (~33.8°N, 44.2°E). Raw water is lifted from the river by low-lift pumps, dosed with aluminium sulfate (alum) at the rapid-mix chamber, passed through horizontal-flow flocculation and sedimentation basins, filtered through rapid gravity sand filters, and finally disinfected with chlorine gas before storage in a clear-water reservoir and pumping to the distribution network (Fig. 1). No advanced treatment stages (softening, activated-carbon adsorption, membrane filtration) are present.

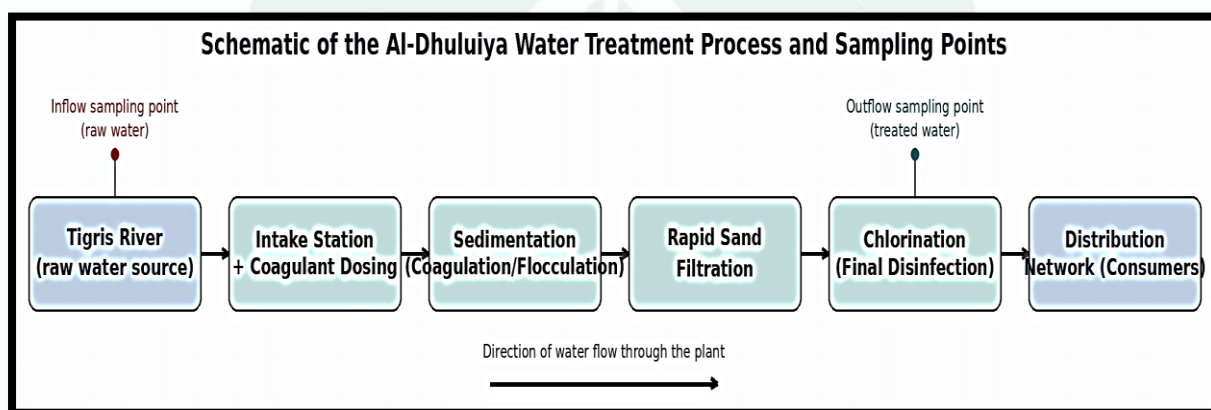


Fig. 1. Schematic of the Al-Dhuluiya water treatment process train, showing influent and effluent sampling locations.

3.2 Sampling

One composite grab sample was collected each month (2024-2025) at each of two fixed locations: (i) the raw-water inlet channel, downstream of the river intake screens and immediately upstream of the coagulant dosing point, and (ii) the

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treated-water outlet, taken from the chlorinated supply just before entry into the distribution system. Sampling covered twelve consecutive months (2024-2025) from November through October, capturing the low-flow summer period, the autumn recession, the winter minimum, and the spring flood season. No samples were lost or rejected during the study period.

3.3 Analytical Methods

Parameters were selected to cover the full scope of IQS 417 and WHO physical, chemical, and disinfection requirements for drinking water. Colour was measured by the platinum-cobalt visual comparison method; turbidity by calibrated nephelometry (NTU); pH electrometrically with a temperature-compensated meter; TDS gravimetrically after filtration and evaporation at 180 °C; total hardness as CaCO₃ by EDTA titrimetry; sulfate by the turbidimetric barium sulfate method; nitrite and nitrate by diazotisation and cadmium-reduction spectrophotometry respectively; chloride by argentometric titration (Mohr method); calcium and magnesium by sequential EDTA titrimetry; and free residual chlorine in outlet samples only, by the DPD colorimetric method. All procedures followed the 23rd edition of Standard Methods [8].

3.4 Regulatory Benchmarks

Effluent results were compared against the Iraqi Drinking Water Standard IQS 417 [7], WHO Guidelines for Drinking-water Quality (4th edition, 2017) [4], US EPA National Primary and Secondary Drinking Water Regulations [5], and EU Drinking Water Directive 2020/2184 [6]. Applicable limits are given in Table 1.

3.5 Removal Efficiency

For each parameter except pH, removal efficiency (RE, %) was calculated as:

$$RE (\%) = [(C_{in} - C_{out}) / C_{in}] \times 100$$

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where C_{in} and C_{out} are the twelve-month mean concentrations at the inlet and outlet respectively. Because pH does not have a maximum removal limit, but instead is a permissible range, pH was not assigned a removal efficiency, and because the change in pH is related to equilibrium chemistry, not to a mass-removal process, it was not included.

3.6 Water Quality Index

Monthly WAWQI scores were computed at both inlet and outlet following Horton [1] as modified by Brown et al. [2]:

$$Q_n = [(V_n - V_{io}) / (S_n - V_{io})] \times 100 ; W_n = K / S_n ; K = 1 / \sum(1/S_n)$$

V_n is the measured concentration of parameter n ; V_{io} is the ideal (background) value, which is zero for all the parameters except pH ($V_{io} = 7.0$); S_n is the permissible limit of the IQS 417; and K is a proportionality constant normalising the unit weights so that their sum equals unity. The overall index for each sample is the sum of all the individual indices divided by the sum of all the weights: $WAWQI = \sum(W_n Q_n) / \sum W_n$. Nine parameters were taken into consideration: colour, turbidity, pH, TDS, hardness, sulfate, nitrite, chloride and nitrate. Ca, Mg, and FRC were omitted because they don't have independent limiting values to be compared to the Q_n formula in IQS 417. The classification was based on the conventional five tier scale, 0-25 (Excellent), 26-50 (Good), 51-75 (Poor), 76-100 (Very poor), and >100 (Unsuitable for drinking) [2,3].

3.7 Statistical Analysis

All parameters were calculated for both sample streams using descriptive statistics (mean, SD, min and max). The significance of the inlet–outlet concentration differences of each inlet–outlet was tested by performing a two-tailed paired samples t-test to determine the significance level at $\alpha = 0.05$ (df = 11, with the twelve monthly paired values the unit of analysis). Pearson correlation analyses were done between inlet parameters to determine common

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hydrochemical signals. All calculations were done in python 3, using NumPy 1.24 and SciPy 1.10.

Table 1. Applicable drinking-water quality limits under four regulatory frameworks.

Parameter	IQS 417	WHO (2017)	US EPA	EU 2020/2184
Colour (TCU)	10	15	15	Acceptable (consumer)
Turbidity (NTU)	5	5	1*	1*
pH	6.5–8.5	6.5–8.5	6.5–8.5	6.5–9.5
TDS (mg/L)	1000	1000	500	Not specified**
Hardness as CaCO ₃ (mg/L)	500	—	—	—
Sulfate (mg/L)	400	250	250	250
Nitrite (mg/L)	3	3	1 (as N)	0.5
Chloride (mg/L)	250	250	250	250
Nitrate (mg/L)	50	50	44.3 (as NO ₃)	50
Free residual Cl (mg/L)	0.2–0.5	≤ 5 (guideline)	≤ 4 (MRDL)	—

(*) Operational benchmark at plant outlet; stricter values apply under optimised coagulation rules. (**) EU Directive uses electrical conductivity (2500 μ S/cm) as a TDS surrogate.

4. Results and Discussion

Results are reported parameter-by-parameter, by physicochemical class, followed by a summary of statistical significance, inter-parameter correlation analysis, WAWQI assessment and a comparison with the multi-std compliance.

4.1 Overview of Inlet and Outlet Water Quality

Table 2 shows the descriptive statistics for all 12 parameters in both sampling locations. The large range of inlet turbidity (4.6–125.0 NTU, CV = 101%) dwarfed the range of dissolved parameters (CV for TDS: 13%; for chloride: 23%) and is a reflection of the large seasonal pulse in suspended-sediment load during

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the spring flood in April. The variability of outlet water was significantly lower (Turbidity CV of 58% and TDS CV of 10%), showing that the treatment process reduces, but does not remove, monthly variations in the supplied water.

Table 2. Descriptive statistics and removal efficiency for all monitored parameters (n = 12 monthly paired samples). RE = removal efficiency.

Parameter	Inlet Mean ± SD	Inlet Range	Outlet Mean ± SD	Outlet Range	RE (%)
Colour (TCU)	2.17 ± 0.58	2.00–4.00	2.17 ± 0.58	2.00–4.00	0.0%
Turbidity (NTU)	31.78 ± 32.11	4.58–125.00	2.27 ± 1.31	0.50–4.50	92.8%
pH	8.07 ± 0.12	8.00–8.40	7.98 ± 0.05	7.90–8.00	n/a
TDS (mg/L)	485.83 ± 62.59	360.00–570.00	232.08 ± 23.57	195.00–265.00	52.2%
Hardness (mg/L)	162.25 ± 25.44	95.00–186.00	100.00 ± 10.66	80.00–110.00	38.4%
Sulfate (mg/L)	142.00 ± 26.17	91.00–179.00	79.58 ± 4.50	70.00–85.00	44.0%
Nitrite (mg/L)	0.37 ± 0.14	0.16–0.62	0.10 ± 0.06	0.01–0.22	73.6%
Chloride (mg/L)	57.08 ± 13.03	34.00–75.00	20.33 ± 1.67	18.00–22.00	64.4%
Nitrate (mg/L)	2.91 ± 0.91	1.30–4.20	1.15 ± 0.58	0.58–2.55	60.4%
Calcium (mg/L)	88.08 ± 10.70	67.00–100.00	61.67 ± 15.57	35.00–80.00	30.0%
Magnesium (mg/L)	30.83 ± 7.30	21.00–50.00	23.42 ± 9.72	12.20–45.00	24.0%

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Outlet measurements of free residual chlorine were the only measurements taken, with an annual average of 0.48 ± 0.16 mg/L (range: 0.30–0.80 mg/L). The majority of values were in the 0.2–0.5 mg/L band recommended for residual maintenance in a distribution system, with a value of 0.80 mg/L in August which was above the upper limit of this range and could lead to complaints at points of use. This scatter indicates that the chlorine dose is not maintained at a strict set-point, but is rather varied seasonally (or in response to fluctuations in demand).

4.2 Turbidity, Colour, and pH

April's turbidity reading of 125 NTU at the inlet is more than eight times the next highest value (Jan: 14.7 NTU) and reflects the arrival of snowmelt-derived flood water from upstream. Despite this, the outlet recorded only 3.5 NTU in that same month — well within the 5 NTU limit — and the annual mean outlet turbidity was 2.3 ± 1.3 NTU. Overall removal averaged 92.8%, the highest of any parameter in the study, and the inlet–outlet difference was statistically significant at the 1% level ($t = 3.21$, $p = 0.008$). Two months (May, at 4.5 NTU) approached but did not breach the 5 NTU limit. The data therefore confirm that the Al-Dhuluiya plant's coagulant-dosing system responds adequately to a near order-of-magnitude turbidity event, which is perhaps the most operationally demanding test a surface-water plant on this river can face [10,11].

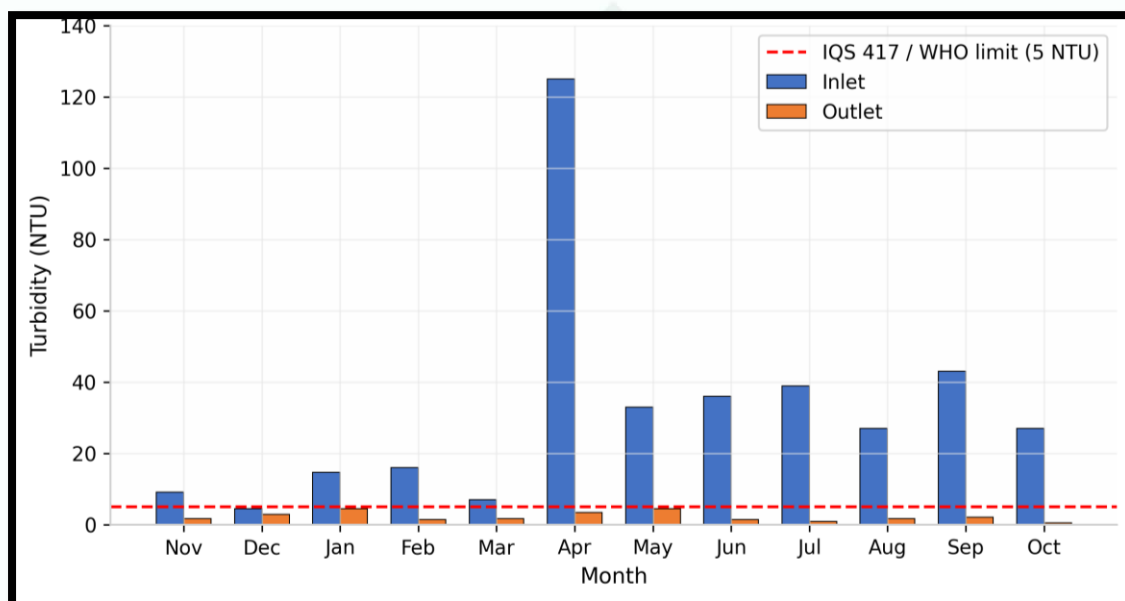
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(Fig. 2) Monthly inlet and outlet turbidity against the IQS 417/WHO limit of 5 NTU.

Colour showed no net removal across the year (inlet mean: 2.17 TCU; outlet mean: 2.17 TCU; efficiency = 0%). Raw-water colour was already well below the IQS 417 threshold of 10 TCU in every month, meaning the process had nothing to act upon in this regard. Inlet–outlet differences were uniformly zero and the t-test was therefore inapplicable. Mean pH fell slightly from 8.07 ± 0.12 to 7.98 ± 0.05 , a change that was statistically significant ($t = 2.56$, $p = 0.026$) but almost certainly a by-product of alum addition and chlorination rather than any targeted pH-control step; both values lie well within the 6.5–8.5 permissible range throughout.

4.3 Total Dissolved Solids

TDS was halved, on average, by treatment: the inlet mean of 485.8 ± 62.6 mg/L dropped to 232.1 ± 23.6 mg/L at the outlet (removal 52.2%; $t = 12.62$, $p < 0.001$).

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There were no detectable instances of high mineralisation, as all the monthly values were below the 1000 mg/L IQS/WHO limit for both sites. The reduction in ~250 mg/L is not as simple as it sounds; conventional alum treatment can co-precipitate some of the silica, natural organic matter, and divalent cations with the floc; and the high spring discharge adds to the dilution of the dissolved load, so the outlet trend is a result of both.

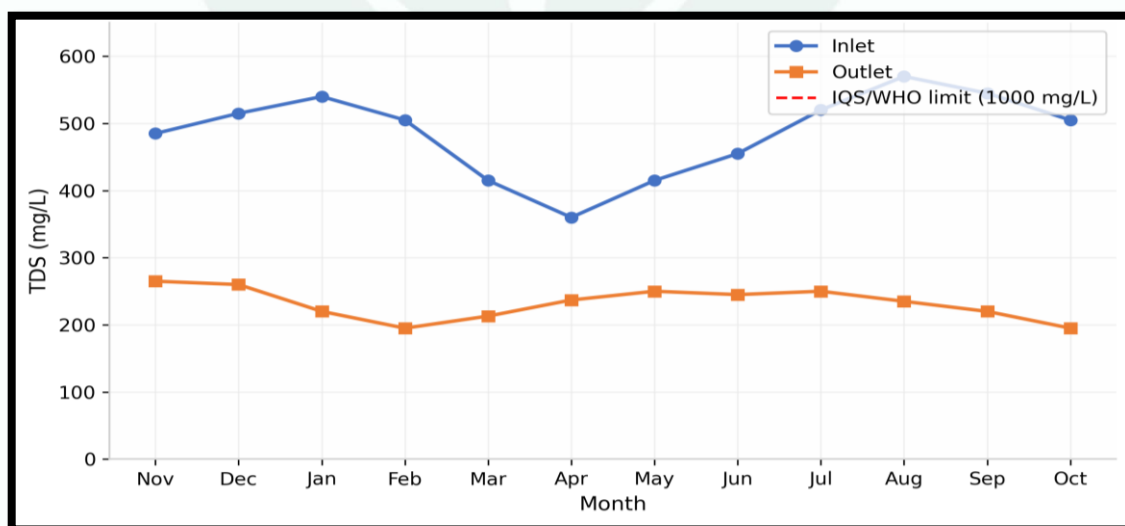


Fig. 3. Monthly inlet and outlet TDS against the IQS/WHO limit of 1000 mg/L.

4.4 Total Hardness, Sulfate, Chloride, and Nitrate

Total hardness at the inlet ranged from 95 to 186 mg/L as CaCO_3 , with a mean of 162.3 ± 25.4 mg/L — well below the IQS 417 limit of 500 mg/L. Treatment reduced this to 100.0 ± 10.7 mg/L (removal 38.4%; $t = 8.14$, $p < 0.001$). Sulfate fell from 142.0 ± 26.2 to 79.6 ± 4.5 mg/L (removal 44.0%; $t = 8.49$, $p < 0.001$), remaining far below the IQS 417 limit of 400 mg/L and the stricter WHO/US EPA/EU threshold of 250 mg/L. The removal rates for chloride and nitrate were slightly higher (64.4% and 60.4% respectively, $p < 0.001$), possibly because both anions showed a strong correlation with the seasonal dilution signal in the raw

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water (see Section 4.8), whereas the hardness forming cations co-precipitate to a certain extent only, and are therefore not as strongly associated with the dilution signal.

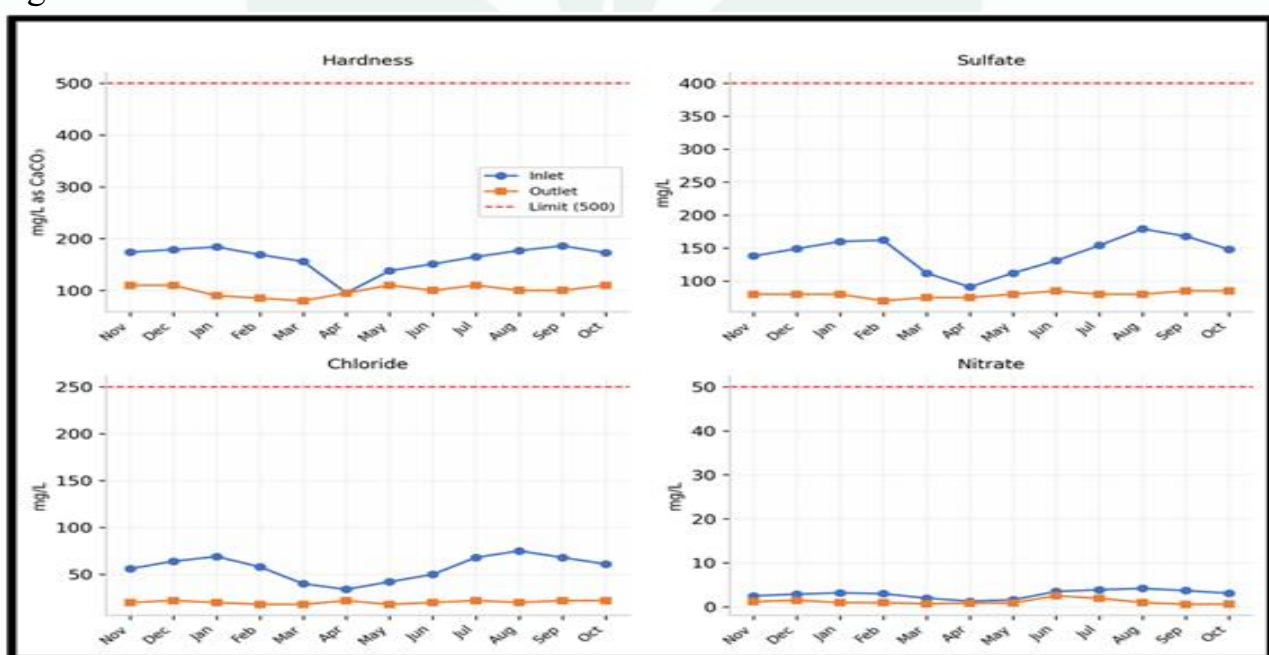


Fig. 4. Monthly inlet and outlet concentrations of total hardness (as CaCO₃), sulfate, chloride, and nitrate.

4.5 Nitrite

Nitrite concentrations in the inlet were low throughout (mean: 0.366 ± 0.145 mg/L; max: 0.62 mg/L, well below the 3 mg/L limit) and were reduced by 73.6% at the outlet (mean: 0.097 ± 0.056 mg/L; $t = 6.44$, $p < 0.001$). This is probably because of chlorination, which oxidizes NO_2^- to NO_3^- quickly; the residual chlorine held at the outlet can then remove most of the nitrite load regardless of the coagulation–filtration load.

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4.6 Calcium and Magnesium

Calcium and magnesium, as the two cations that constitute total hardness, followed a similar trajectory to the hardness result. Calcium fell 30.0% ($88.1 \pm 10.7 \rightarrow 61.7 \pm 15.6$ mg/L; $t = 7.45$, $p < 0.001$) and magnesium fell 24.0% ($30.8 \pm 7.3 \rightarrow 23.4 \pm 9.7$ mg/L; $t = 3.14$, $p = 0.009$). These decreases are less than for the ionic anions listed above, which agree with the general trend towards a lower flocculation affinity of divalent cations compared to particulate-borne material at the doses of alum typical of conventional treatment. Interestingly, the outlet magnesium concentration was also more variable than inlet concentration (outlet SD: 9.7 vs inlet SD: 7.3 mg/L; outlet range: 12.2–45.0 mg/L), indicating that the amount of magnesium incorporated into the floc was influenced by the month-to-month variation in coagulant dose or reaction pH, which is a process control question that could be further investigated.

4.7 Free Residual Chlorine

Free residual chlorine in the treated effluent averaged 0.48 ± 0.16 mg/L across the year (range: 0.30–0.80 mg/L). The target band for most Iraqi distribution systems is 0.2–0.5 mg/L; the plant met this target in nine of twelve months. The three months above 0.5 mg/L (December: 0.80, November and August: 0.60 mg/L) may reflect conservative chlorine dosing during warmer or higher-demand periods. While no values exceeded the IQS 417 upper advisory of 0.5 mg/L for aesthetic reasons, the August peak of 0.80 mg/L merits operational note as a potential taste-and-odour concern.

4.8 Statistical Significance of Inlet–Outlet Differences

Table 3 gives the paired t-test output for all nine quantitative parameters. All nine returned p-values below 0.05, with TDS, hardness, sulfate, nitrite, chloride, nitrate, and calcium all yielding $p < 0.001$. Magnesium was significant at the 1% level ($p = 0.009$), and turbidity at the 1% level ($p = 0.008$). Colour was untestable

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owing to zero-variance differences. The pattern is consistent with a treatment train that removes or transforms almost all parameters to a statistically detectable degree.

Table 3. Paired-samples t-test results (df = 11, n = 12 monthly pairs).

Parameter	t-statistic	p-value	Outcome ($\alpha = 0.05$)
Turbidity	3.21	0.008	Significant
TDS	12.62	< 0.001	Significant
Total hardness	8.14	< 0.001	Significant
Sulfate	8.49	< 0.001	Significant
Nitrite	6.44	< 0.001	Significant
Chloride	10.13	< 0.001	Significant
Nitrate	6.79	< 0.001	Significant
Calcium	7.45	< 0.001	Significant
Magnesium	3.14	0.009	Significant

4.9 Inter-Parameter Correlations in Raw Water

The Pearson correlation matrix for inlet parameters (**Fig. 5**) shows a tight positive cluster linking TDS, hardness, sulfate, chloride, nitrate, and calcium, with pairwise r values of 0.72–0.99. This group tracks the overall dissolved-ion load of the river, which is diluted during high-discharge (high-turbidity) months and concentrated during low-flow periods — hence the strong negative correlations between turbidity and the same group ($r = -0.36$ to -0.80). There is weak correlation of the other parameters with either magnesium ($|r| \leq 0.29$) or nitrite ($|r| \leq 0.29$), suggesting the presence of more localised and/or episodic sources for these two species, as well as the highest unexplained variability among all of the parameters for outlet magnesium (Section 4.6).

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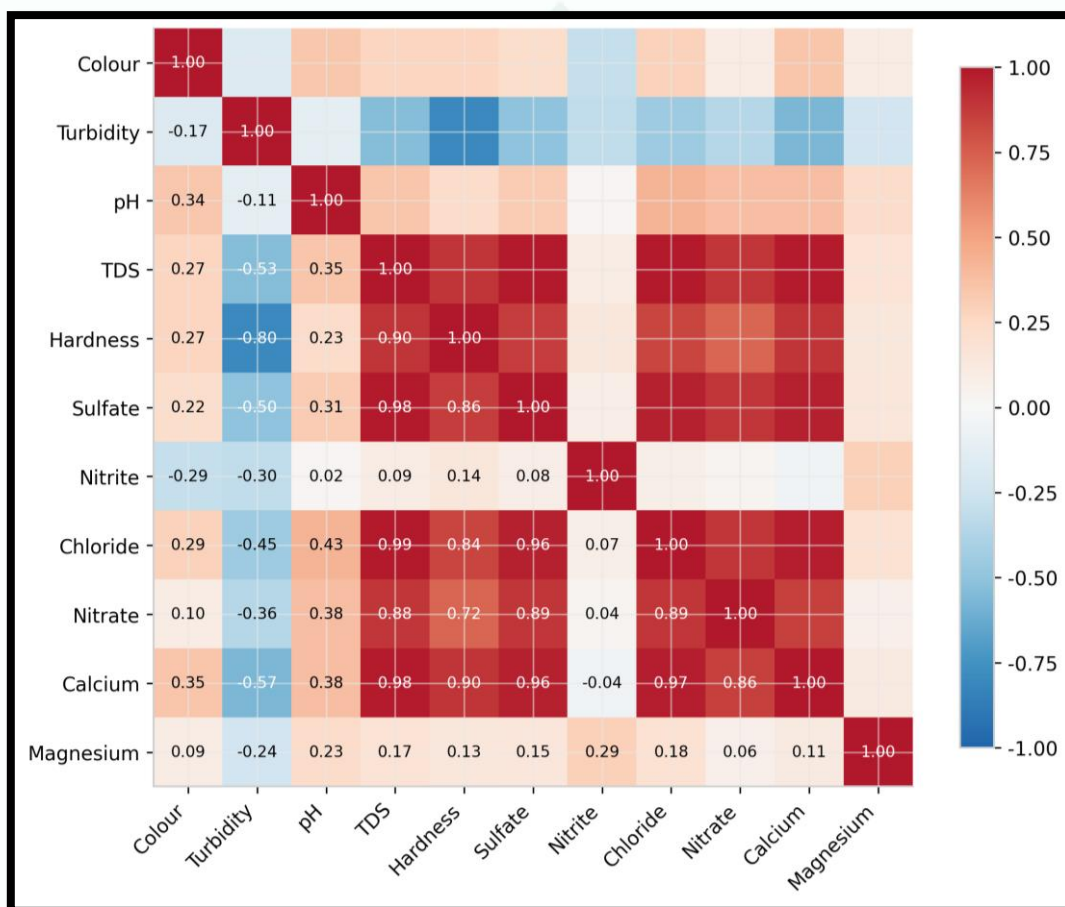


Fig. 5. Pearson correlation matrix for inlet (raw) water parameters.

4.10 Summary of Removal Efficiencies

When the nine parameters are ranked by mean removal efficiency, turbidity (92.8%) is well in front of the pack. Nitrite comes next (73.6%), boosted by chlorine oxidation, followed by chloride (64.4%), nitrate (60.4%), TDS (52.2%), sulfate (44.0%), and total hardness (38.4%). The lowest values of the parameters with positive removal are calcium (30.0%) and magnesium (24.0%). The total distribution is shown in **Fig. 6**.

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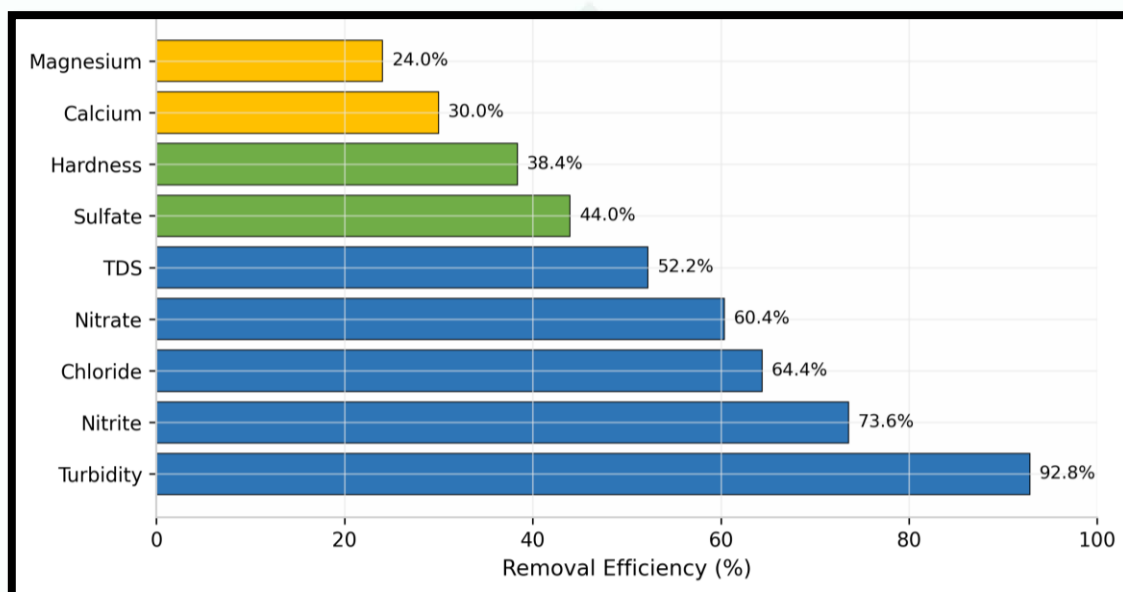


Fig. 6. Mean removal efficiency (%) by parameter over the twelve-month study period.

4.11 Water Quality Index

Raw-water WAWQI scores ranged from 31.9 (December) to 656.7 (April) over the twelve months (mean $\pm$ SD: 182.1 ± 158.8 ; median: 158.4). The April value contributes to most of the statistical spread; the average for the other 11 months is 139.1 and the median is 100.7 which fall in the "Poor" to "Very poor" range, not in the "Unsuitable" range. This is significant because the WAWQI mean is not a good indicator of the typical inlet quality if one extreme month so skews the distribution. The raw water at Al-Dhuluiya would grade "Very poor" for drinking in typical month without treatment based on median.

Treated-water WAWQI scores ranged from 16.5 (October) to 40.3 (January), with a mean of 25.9 ± 8.6 and a median of 23.2. None of the 12 months were rated "Poor" or higher, all were either "Excellent" or "Good". The results confirm the treatment process from an integrated-index view: year-round, the plant produced

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effluent that falls within the good and excellent quality range of the WAWQI scheme regardless of the inlet variability. The monthly index trajectories, together with the classification-frequency distribution, are shown in **Fig. 7**.

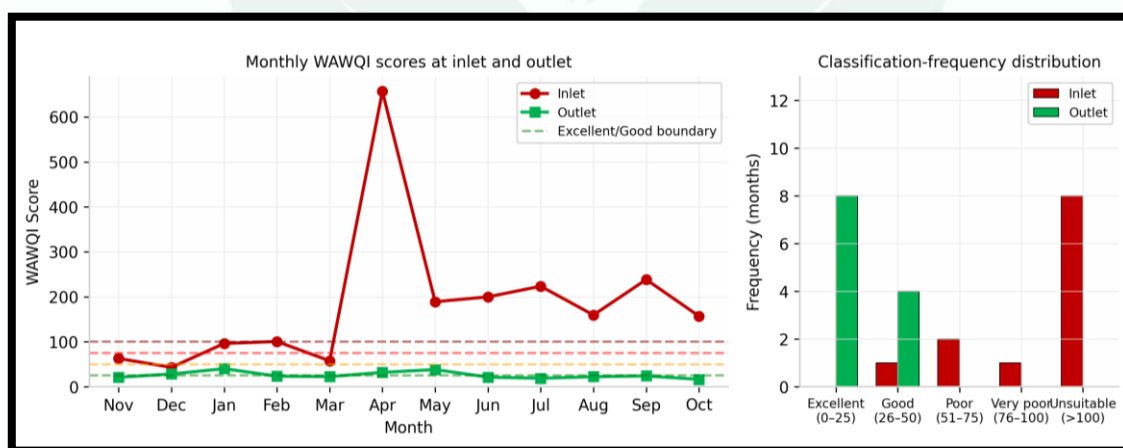


Fig.7. Monthly WAWQI scores at inlet and outlet (left), and classification-frequency distribution (right).

4.12 Compliance with International Standards

Table 4 sets out the applicable limits under IQS 417, WHO 2017, US EPA, and EU 2020/2184 for the parameters measured in this study. Fig.8 compares mean effluent concentrations of six key parameters against all four frameworks. For TDS, sulfate, chloride, and nitrate, effluent means were below every applicable limit by a comfortable margin, regardless of which framework is used. Turbidity is the only parameter where the picture changes depending on which standard is applied: the annual outlet mean of 2.27 NTU comfortably satisfied the 5 NTU IQS/WHO ceiling in every month, but exceeded the 1 NTU operational benchmark used by the US EPA (under the Surface Water Treatment Rule) and adopted in the EU Directive in five months of the twelve. This tighter threshold reflects a precautionary approach to *Cryptosporidium* and *Giardia* control through

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optimised coagulation–filtration, rather than any chemical toxicity concern, and its exceedance at Al-Dhuluiya should be read as a signal to tighten coagulant-dose control during moderate-turbidity months rather than as evidence that the treated water is unsafe.

Table 4. Regulatory limits used for treated-water benchmarking.

Parameter	IQS 417	WHO (2017)	US EPA	EU 2020/2184
Color (TCU)	10	15	15	Acceptable (consumer)
Turbidity (NTU)	5	5	1*	1*
pH	6.5–8.5	6.5–8.5	6.5–8.5	6.5–9.5
TDS (mg/L)	1000	1000	500	Not specified**
Hardness as CaCO ₃ (mg/L)	500	—	—	—
Sulfate (mg/L)	400	250	250	250
Nitrite (mg/L)	3	3	1 (as N)	0.5
Chloride (mg/L)	250	250	250	250
Nitrate (mg/L)	50	50	44.3 (as NO ₃)	50
Free residual Cl (mg/L)	0.2–0.5	≤5 (guideline)	≤ 4 (MRDL)	—

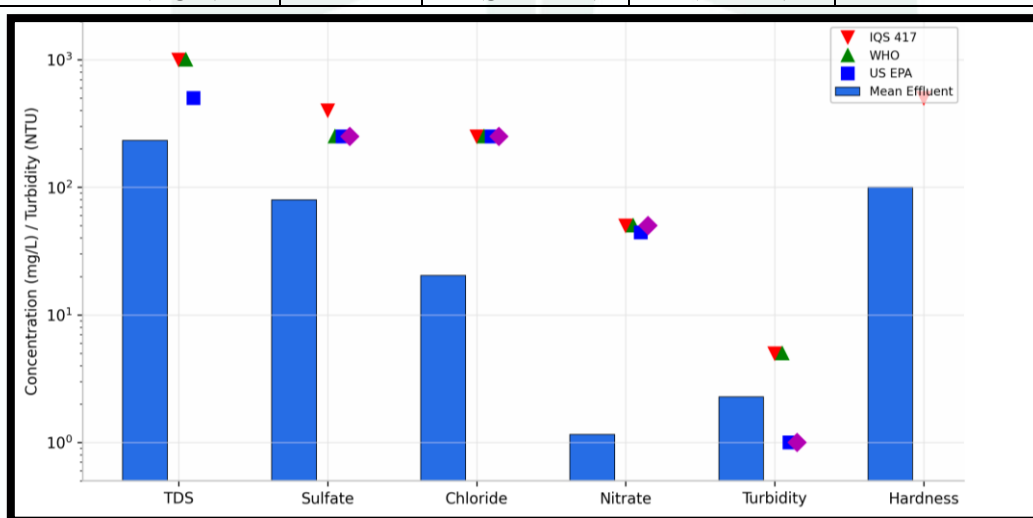


Fig.8. Mean effluent and classification-frequency concentrations of six key parameters plotted against limits from four regulatory framework.

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5. Conclusions

1. Effective control of turbidity was maintained throughout the year. The plant in April cleaned a peak inlet turbidity of 125 NTU to 3.5 NTU at the outlet, and had an annual mean outlet turbidity of 2.3 NTU (5 NTU IQS/WHO limit). Mean removal efficiency was 92.8% ($t = 3.21$, $p = 0.008$).
2. All nine chemically variable parameters had statistically significant reductions ($p < 0.05$) with removal efficiencies ranging from 24.0% (Mg) to 73.6% (NO_2). No parameter was violated in any month for treated water with respect to the 12 parameters measured in both the IQS and WHO standards.
3. The WAWQI went from an average "Very poor" (median: 158.4) inlet to a steady "Good" or "Excellent" (median: 23.2) outlet, which gives an integrated quality measure, matching the individual parameter results.
4. All twelve months of outlet turbidity compliance met the IQS/WHO 5 NTU limit, and exceeded the more demanding US EPA/EU operational benchmark of 1 NTU in five months, suggesting that operation of coagulation optimisation during intermediate turbidity conditions can further meet the most stringent international standards.
5. Inter-parameter correlation analysis indicated that the most significant hydrochemical signal in Tigris water at this site is the dilution effect associated with flow, in which factors such as TDS, hardness, sulfate, chloride, nitrate, and calcium show the highest degree of correlation; and magnesium remains relatively independent of the other water parameters, which is important for operational water-quality prediction and coagulant-dosing models.

6. Limitations

- The one composite grab sample per month at each location ($n = 12$ pairs) is adequate for seasonal characterisation and parametric statistical testing, but not for within-month variability, diurnal cycles in raw water quality or transient treatment upsets.

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A greater number of samples taken during the spring flood period especially would provide a more detailed analysis of the coagulant-dosing response.

- Microbiological parameters (total and thermotolerant coliforms, *E. coli* and protozoan indicators (*Cryptosporidium*, *Giardia*) were not monitored and will not be discussed here. The lack of microbial data is an important missing limitation of the overall safety assessment because the main function of final chlorination is to destroy microorganisms.
- Relative ranking of the months would remain unchanged while numerical scores would vary if the WHO or EU limits were used for the IQS 417 instead of the permissible values. As a result of this heavy weighting (due to the relatively low limit for the IQS of 5 NTU, compared to the relatively high limit for the TDS of 1000 mg/L), the April flood event is driving the inlet mean WQI up. Users should be aware of this skewness when using Table 2 and Fig. 7.
- All results are site-specific and period-specific. Extrapolation to other plants on the Tigris, or to different hydrological years, requires caution.

7. Recommendations

1. Monitoring on-line (continuous) should be used instead of monthly grab-sample monitoring of turbidity at the plant inlet and automated coagulant dosing should be evaluated as a cost-effective method to ensure outlet turbidity remains below 1 NTU during flood events, which will place the plant in compliance with US EPA and EU plant operational benchmarks.
2. There is a need for a root cause investigation of the monthly variation of effluent magnesium (12.2 – 45.0 mg/L). They may be a result of differing alum doses, changes in the flocculation basin residence time, and/or inconsistent filter backwash schedules — process logs should be compared to the monthly chemistry data to determine which is the most likely cause.
3. The chlorine dose should be considered to decrease the frequency of outlet residual > 0.5 mg/L, especially during the cooler months when demand is less

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and contact time longer. Residual monitoring at the end of the distribution system (not just at the plant outlet) would give a better picture of water quality at the consumers' tap.

4. The routine monitoring programme should be complemented with the microbiological and the heavy-metal parameters as these are to be included as a priority to complete the safety profile beyond the physicochemical parameters dealt with here.

5. Automated trend detection by a digital process-control and quality-records database for the plant, and the availability of the data infrastructure for future dosing-optimisation algorithms, would be greatly facilitated.

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References

- [1] Horton, R.K., 1965. An index-number system for rating water quality. J. Water Pollut. Control Fed. 37(3), 300–306.
- [2] Brown, R.M., McClelland, N.I., Deininger, R.A., Tozer, R.G., 1970. A water quality index – do we dare? Water Sewage Works 117, 339–343.
- [3] Uddin, M.G., Nash, S., Olbert, A.I., 2021. A review of water quality index models and their use for assessing surface water quality. Ecol. Indic. 122, 107218. <https://doi.org/10.1016/j.ecolind.2020.107218>
- [4] World Health Organization, 2017. Guidelines for Drinking-water Quality, 4th ed. (1st addendum). WHO, Geneva.
- [5] US Environmental Protection Agency. National Primary and Secondary Drinking Water Regulations, 40 CFR Parts 141 and 143.

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<https://eurekaoa.com/index.php/7>

- [6] Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast). Off. J. Eur. Union L 435, 1–62.
- [7] Iraqi Central Organisation for Standardisation and Quality Control (COSQC), 2001. Iraqi Standard No. 417 for Drinking Water, 2nd revision. Baghdad.
- [8] American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF), 2017. Standard Methods for the Examination of Water and Wastewater, 23rd ed. APHA, Washington, DC.
- [9] Davis, M.L., 2010. Water and Wastewater Engineering: Design Principles and Practice. McGraw-Hill, New York.
- [10] Khlaif, O.A., Abdulrazzaq, K.A., Mohammed, A.H., 2022. Performance evaluation the turbidity removal efficiency of Al-Muthana water treatment plant. J. Eng. 28(3), 1–13. <https://doi.org/10.31026/j.eng.2022.03.01>
- [11] Shihab, A.S., Ahmad, A.M., 2020. Performance study of tube settlers in removing low turbidity from the Tigris River water using a bench scale model. Tikrit J. Eng. Sci. 27(4), 1–7.
- [12] Al-Musawi, T.J., Mohammed, I.A., Atiea, H.M., 2017. Optimum efficiency of treatment plants discharging wastewater into river, case study: Tigris river within Baghdad. MethodsX 4, 445–456. <https://doi.org/10.1016/j.mex.2017.10.009>