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Evaluation of Al-Thagher Wastewater Treatment Plant

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Abstract
This study aims to evaluate the performance of the sewage treatment plant in Al-Thagher city, in the north of Basrah governorate, the southern part of Iraq. The plant's performance was estimated based on an analysis of influent and effluent wastewater quality data that represented the monthly averages from Feb. 2017 to Dec. 2018. The results show that the values of temperature (T), pH, ammonia (NH_3–N), chemical oxygen demand (COD) and biological oxygen demand (BOD) in all collected samples from the effluent of the plant met the Iraqi water quality standard (IWQS), whereas the values of electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), sulfate (SO_4^{-2}), chloride (Cl^{-1}) and phosphate (PO_4–P) met the Iraqi water quality standard (IWQS) in some months and did not meet the standard in other months. The average removal efficiencies were in the following order: COD (77.12%) > BOD (77.03%) > TSS (62.26%) > NH_3–N (59.99%) > PO_4–P (12.42%) > Cl^{-1} (1.97%). The removal percentages for the remaining parameters had negative values. The Canadian Council of Ministers of the Environment water quality index (CCME WQI) value of the treated water was 51.80 and classified as "marginal." The coefficients of determination between each parameter in influent or effluent were calculated. Finally, linear regression equations between these parameters were formulated so that the value of one parameter could be used to predict the value of a different parameter.

Keywords
sewage treatment plants, performance evaluation, wastewater characteristics, BOD, COD, TSS, CCME WQI

1 Introduction

Wastewater is created from residential, institutional, commercial and industrial activities [1]. Wastewaters are commonly polluted with physical, chemical, and biological compounds, all of which have a significant negative effect on the environment, with the potential to destroy many habitats and irreversibly harm ecosystems [2]. The release of raw wastewater into watercourses has negative impacts on the environment and human health. Hence, wastewater should be properly treated before it is discharged into surface water or land to protect the health of inhabitants of both rural and urban communities. Therefore, wastewater is collected and transported via a network of pipes to a wastewater treatment plant (WWTP) [3].

Typically, wastewater treatment involves three stages, called primary, secondary and tertiary treatment. The degree of reduction of biochemical oxygen demand (BOD) and total suspended solids (TSS), which constitute organic waste, is the general yardstick for measuring the efficiency of WWTPs. Improper operation of WWTPs may bring serious environmental problems, as its effluent is discharged to a water body [4]. The efficiency of wastewater treatment is a basic indicator of WWTP function [5]. WWTP performance must be evaluated to assess effluent efficiency, satisfy treatment criteria, and determine whether the treatment plants can accommodate higher hydraulic organic loadings [6]. Established facilities may be modified to accommodate higher hydraulic and organic loads, but meeting higher treatment standards typically necessitates substantial expansion or alteration of existing facilities [7]. Frequent field and laboratory measurements are important tools for proper treatment process control and management [8]. Much research worldwide has investigated and analyzed WWTP effectiveness, including studies in the United States [9–11] and Iraq [12–14].

The water quality index (WQI) provides a single dimensionless value using mathematical equations that indicate the overall water quality under specified conditions of time and location depending on various water quality parameters. A WQI is a tool used by scientists, decision-makers, stakeholders, and governmental authorities

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and agencies to facilitate smart management of water quality issues [15–17]. Since 1967, numerous scholars and agencies have presented many water quality indices for water quality assessment [17]. The most widely used WQIs were developed by the National Sanitation Foundation (NSF WQI) and the Canadian Council of Ministers of the Environment (CCME WQI) [18]. In 2021, Uddin et al. reviewed WQI applications found in literature published from 1960 to 2019, and they concluded that the CCME and NSF water quality indices have been used in more than 50% of the reviewed studies [17].

The advantages of the CCME WQI over other water quality indices are its ease of application, flexibility in choosing the lowest water quality parameters (only four) to be included in the model, flexibility in the selection criteria, relative strictness compared to other indices, suitability for water quality evaluation in specific places, compliance with various legal standards for various water usage, and tolerance for missing data [17–19]. Therefore, the CCME WQI has been widely applied to many surface and groundwater bodies in Iraq [20, 21] and other countries [22–27]. Recently, the CCME WQI has been used to evaluate the quality of treated water [28–34]. Thus, WQI is also a helpful and useful tool for researchers and decision-makers to monitor and assess the treated wastewater quality for any purpose [33, 34].

This research aims to examine the performance of the Al-Thagher WWTP in Basrah Governorate, in southern Iraq. This evaluation could be used to facilitate effluent quality assessment or optimal process control of the plant. Influent characterization was conducted to determine wastewater strength. All studied parameters (TSS, COD, BOD, temperature (T), pH, electrical conductivity (EC), total dissolved solids (TDS), sulfate (SO_4^{-2}), chloride (Cl^{-1}), ammonia (NH_3–N), and phosphate (PO_4–P)) of the effluent were compared with the Iraqi water quality standard (IWQS) to determine whether they meet this standard. Then, the CCME WQI was calculated for the effluent. This study also investigated the strength of the correlation between pairs of parameters to establish a linear regression between them.

2 Materials and methods

2.1 Al-Thagher WWTP

The Al-Thagher WWTP is located at Al-Thagher city in the northern part of Basrah governorate on the Tigris River (31°8'41"N, 47°26'43"E), as shown in Fig. 1. The plant treats wastewater from the city of Al-Thagher. The Al-Thagher

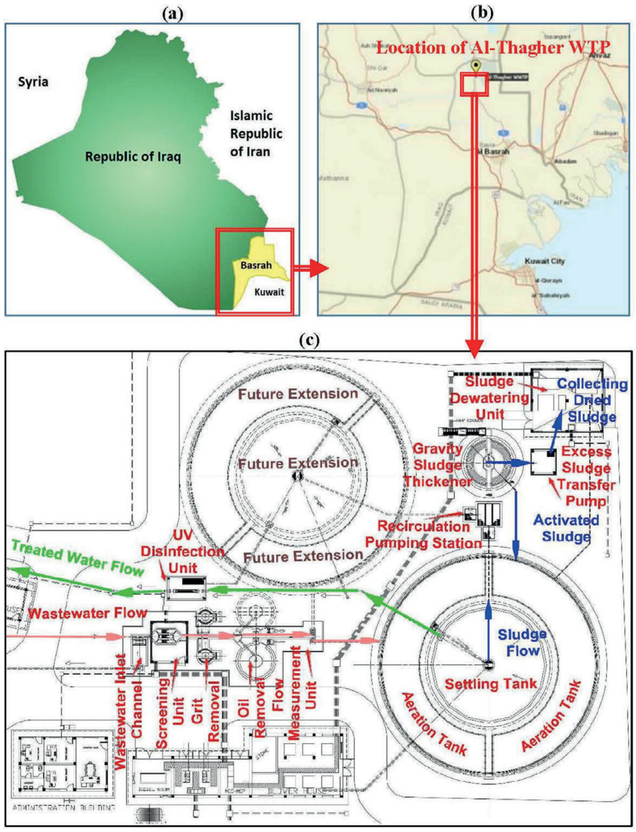

Fig. 1 Study Area: (a) Iraqi Map, (b) Basrah Map, (c) Al-Thagher WWTP layout

WWTP was built in 2016 and designed to work until 2036. The total area of the treatment plant is 3600 m^2, and it serves more than 6000 people in one of the biggest governorates of the country. The output capacity of the treatment plant is 2800 m^3/day and may reach 3100 m^3/day at peak [35].

The plant uses the extended aeration-activated sludge (EAAS) process. Extended aeration plants are designed to require the plant operator to manage minimal routine housekeeping and operational tasks. The designed process units include one sand trap to filter rain wastewater, an inlet wastewater channel, a screening room, a grit chamber, a flow meter channel, a wastewater distribution box, an aeration unit based on extension aeration, a settling tank with sludge scraper, a UV disinfection channel, a gravity sludge thickener, a thickened sludge pump station, a polyelectrolyte dosing station and a sludge mixing tank with polyelectrolyte and sludge belt filter press, as shown in Fig. 2. A circular design is used to optimize the space; the main clarifier is located in a circular basin. The aeration tank surrounds the clarifier on the outside and is concentric to the clarifier. A scraper mechanism is installed inside the main clarifier to collect and remove sludge from the bottom. The wastewater is first screened

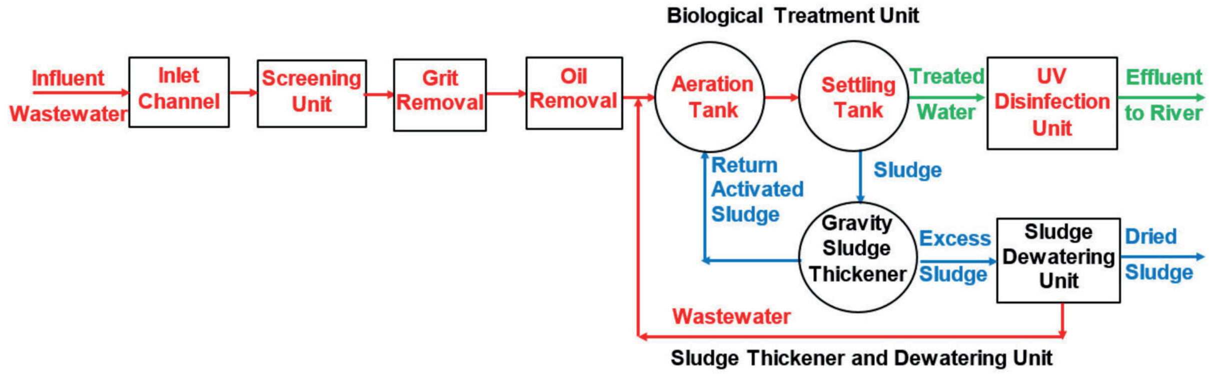

Fig. 2 Treatment processes flow chart of the Al-Thagher WWTP

and then flows into the aeration tank. The main clarifier is used to remove the activated sludge; some amount returns to the aeration tank to seed the incoming wastewater while the remainder is transferred to the sludge digester (Fig. 1(c) and Fig. 2). Sludge is thickened and dewatered on-site. Treated effluent from the plant discharges to a nearby stream [35]. The plant is controlled under the main operation conditions listed in Table 1.

2.2 Data collection and analysis

The data used in this paper were provided from the Al-Thagher WWTP for the period from February 2017 to December 2018. The data represented the average monthly values of the main influent and effluent parameters. The main parameters are T, pH, EC, TDS, TSS, $SO4^{-2}$, Cl^{-1}, NH_3–N, PO_4–P, COD and BOD. Samples were obtained and analyzed at the Al-Basrah WWTP's laboratory. Influent samples were obtained after the grit chamber unit, and effluent samples were taken after the disinfection stage. Standard methods were used to determine the concentration of the parameters [36]. Simple descriptive statistics were used to tabulate and analyze the data.

Table 1 Operating conditions of the Al-Thagher WWTP

Operation Parameter		Value	Unit
SRT	Sludge Retention Time	20–40	day
MLSS	Mixed Liquor Suspended Solids	2000–5000	mg/L
HRT	Hydraulic Retention Time	20–30	hours
Q_r/Q_0	Return Activated Sludge (Qr) as % of Incoming Flow (Q0)	50–150	%
F/M	Food / Microorganisms	0.04–0.1	kg BOD/ kg MLVSS/day
DO	Dissolved Oxygen	2–4	mg/L

3 Results and discussion

3.1 Influent characteristics

Raw wastewater must be characterized to select appropriate treatment technology, design efficient treatment facilities and evaluate the efficiency of different processes. Table 2 shows the concentrations and statistics of the studied parameters in the influent wastewater for 23 months from February 2017 to December 2018. Averages, standard deviations and maximum and minimum values were calculated for the main parameters from the data. Table 3 shows the strong, medium and weak strengths of the compositions of typical municipal wastewater according to Metcalf and Eddy et al. [1].

According to the typical wastewater classification in Table 3, the measured pH values (6.9–7.4) in raw wastewater were within the medium range of typical wastewater value (7–9). The pH values in most months were equal or slightly higher than 7 except for three months (Feb. 2017, Oct. 2018, and Dec. 2018), when the value was less than 7 by 0.1.

The measured electrical conductivity (EC) values (1362–4396 µs/cm) in raw wastewater varied between strong (> 1500 µs/cm) and medium (1000–1500 µs/cm). The EC values in most months were higher than 1500 µs/cm except for two months (May 2017 and Jun. 2017).

The measured total dissolved solids (TDS) concentrations (756–3070 mg/L) in raw wastewater varied between strong (> 1000 mg/L) and medium (500–1000 mg/L). The TDS concentrations in most months were higher than 1000 mg/L except for three months (May 2017, Jun. 2017, and Sep. 2018).

The measured concentrations of SO_4^{-2} (199–1085 mg/L) in raw wastewater were within the strong range (>100 mg/L) of typical wastewater concentrations. The SO_4^{-2} concentrations were higher than 100 mg/L in all months.

Table 2 Influent wastewater characteristics at the Al-Thagher WWTP

Month	T	pH	EC	TDS	TSS	SO_4^{-2}	Cl–1	NH_3–N	PO_4–P	COD	BOD	BOD/COD
Feb-17	16.8±3.2	6.9±0.07	3166±449	1626±402	134±73	386±110	523±75	14.9±5.5	1.4±0.8	85±22	39±19	0.46
Mar-17	21.9±3.0	7.0±0.04	4396±558	2096±346	290±89	441±87	667±53	1.7±1.0	0.4±0.3	187±24	76±17	0.41
Apr-17	26.0±3.7	7.2±0.03	2879±399	1426±457	189±62	320±107	475±89	7.4±4.5	0.3±0.2	218±38	86±22	0.40
May-17	29.7±3.9	7.3±0.05	1362±376	756±377	65±41	199±101	284±71	13.2±6.0	0.3±0.2	228±36	90±21	0.39
Jun-17	34.9±4.4	7.2±0.05	1447±700	957±330	32±14	204±139	338±58	12.0±4.0	2.1±1.5	205±35	81±29	0.39
Jul-17	38.0±3.8	7.1±0.02	1658±721	1260±304	21±13	217±91	393±83	10.8±6.0	3.8±2.1	175±41	72±32	0.41
Aug-17	35.5±4.0	7.2±0.05	1964±646	1416±387	44±19	267±142	341±85	14.9±6.9	3.3±2.1	165±28	75±20	0.46
Sep-17	31.1±2.9	7.3±0.06	2373±727	1566±307	71±29	333±139	290±86	21.2±6.3	2.4±1.2	161±35	85±16	0.53
Oct-17	26.0±3.3	7.2±0.01	3052±574	1840±447	81±47	384±142	370±58	25.5±6.1	1.7±1	190±41	115±23	0.61
Nov-17	20.6±3.4	7.2±0.07	3831±421	2150±243	87±67	429±83	518±68	29.0±5.9	1.2±0.5	242±42	158±26	0.65
Dec-17	18.1±2.8	7.1±0.06	4204±475	2298±423	88±51	455±116	598±70	31.7±6.6	0.9±0.5	271±29	180±27	0.66
Jan-18	18.8±3.2	7.1±0.07	3848±453	2220±427	83±36	465±103	533±72	33.5±7.5	2.9±1.6	242±32	174±20	0.72
Feb-18	20.7±5.0	7.1±0.03	3188±541	2043±394	73±50	471±141	412±90	34.6±4.3	6.5±2.2	189±39	158±26	0.84
Mar-18	23.3±4.7	7.1±0.04	2832±717	1852±453	68±44	473±133	347±54	35.0±5.1	8.5±3	160±22	130±20	0.81
Apr-18	26.4±3.3	7.2±0.02	3302±649	1676±246	354±87	320±146	656±62	16.6±7.0	8.4±3.7	235±25	45±21	0.19
May-18	26.7±2.9	7.2±0.06	2527±563	1402±237	122±93	375±121	555±88	10.6±5.2	10.5±2.1	176±29	70±21	0.40
Jun-18	31.8±3.9	7.0±0.08	2390±539	1036±375	85±41	363±85	494±89	13.0±4.0	19.8±2.2	181±22	100±24	0.55
Jul-18	32.7±3.6	7.1±0.07	2537±556	1558±429	46±36	350±123	489±74	12.0±5.1	8.1±2.7	120±23	70±16	0.58
Aug-18	33.8±4.1	7.4±0.07	2328±508	1092±240	50±38	312±140	421±99	10.2±4.0	9±3.8	148±27	90±20	0.61
Sep-18	31.6±3.1	7.3±0.06	1847±684	830±457	354±81	213±108	428±80	15.1±7.4	10.5±3.4	172±31	80±25	0.46
Oct-18	23.8±3.3	6.9±0.01	3520±492	2520±434	220±87	655±89	591±85	14.7±7.0	8.4±2.8	140±27	60±18	0.43
Nov-18	19.7±3.0	7.1±0.03	3924±511	3070±415	422±70	1085±105	670±87	8.5±4.1	10.2±2.1	315±42	60±25	0.19
Dec-18	15.7±3.5	6.9±0.06	4320±709	2108±381	236±49	645±130	753±92	9.5±4.4	8.4±3.4	118±22	60±32	0.51
Ave.	26.2	7.1	2908	1687	140	407	485	17.2	5.6	188	94	0.51
SD (±)	6.6	0.1	920	578	117	192	131	9.6	4.9	53	40	0.17
Max	38	7.4	4396	3070	422	1085	753	35	19.8	315	180	0.84
Min	15.7	6.9	1362	756	21	199	284	1.7	0.3	85	39	0.19
Class	–	–	S–M	S–M	M–W	S	S	M–W	M–W	M–W	M–W	W

Note: All values (mean ± SD) are expressed in mg/L (ppm) except pH (dimensionless), EC (μs/cm) and temperature (°C).

Table 3 Typical composition and strength type of wastewater [1]

Constituents	Unit	Typical Concentration		
		Strong (S)	Medium (M)	Weak (W)
pH	–	6 to 9	7 to 9	8 to 9
COD	mg/L	1000	500	250
BOD	mg/L	300	200	100
NH_3–N	mg/L	75	45	20
PO_4–P	mg/L	15	10	5
SO_4^{-2}	mg/L	100	50	25
Cl^{-1}	mg/L	50	30	20
TDS	mg/L	1000	500	200
TUR	NTU	1500	1000	500
TSS	mg/L	400	210	120
EC	μs/cm	1500	1000	500

The measured concentrations of Cl^{-1} (284–753 mg/L) in raw wastewater were within the strong range (> 50 mg/L) of typical wastewater concentrations. The Cl^{-1} concentrations were higher than 50 mg/L in all months.

The high concentrations of salt parameters (EC, TDS, SO_4^{-2}, and Cl^{-1}) are due to the saltwater intrusion from the Persian Gulf to the Shatt Al-Arab River, which is the main source of water supply for Al-Thagher city. High salt concentrations in wastewater lead to reduce the performance of biological treatment due to the negative effects of salt on microorganisms [1].

The measured total suspended solids (TSS) concentrations (21–422 mg/L) in raw wastewater varied between the medium (120–400 mg/L) and weak (< 120 mg/L) range of typical wastewater concentrations. The TSS concentrations in 9 months were between 120–400 mg/L (medium) and were less than 120 mg/L (weak) in 14 months.

The measured concentrations of NH_3–N (1.7–35 mg/L) in raw wastewater varied between the medium (20–75 mg/L) and weak (< 20 mg/L) range of typical wastewater concentrations. The NH_3–N concentrations in most months were between 20–75 mg/L (medium) and were less than 20 mg/L (weak) in only seven months (Sep. 2017 to Mar. 2018).

The measured concentrations of PO_4–P (0.3–19.8 mg/L) in raw wastewater varied between the medium (5–15 mg/L) and weak (< 5 mg/L) range of typical wastewater concentrations. The PO_4–P concentrations in some months (Feb. 2017 to Jan. 2018) were between 5–15 mg/L (medium) and were less than 5 mg/L (weak) in other months (Feb. 2018 to Dec. 2018).

The measured concentrations of COD (85–315 mg/L) in raw wastewater varied between medium (250–1000 mg/L) and weak (< 250 mg/L). The COD concentrations in most months were less than 250 mg/L (weak) and were between 250–1000 mg/L (medium) in only two months (Dec. 2017 and Nov. 2018).

The measured concentrations of BOD (39–180 mg/L) in raw wastewater varied between medium (100–300 mg/L) and weak (< 100 mg/L). The BOD concentrations in most months were less than or equal to 100 mg/L (weak) and were between 100–300 mg/L (medium) in only six months (Oct. 2017 to Mar. 2018).

As shown in Table 4, the values of the BOD/COD ratio have been classified into three categories: slowly biodegradable (0.2–0.4), average biodegradable (0.4–0.5) and readily biodegradable (0.5–0.8). In most months, the calculated BOD/COD ratio was equal to or greater than 0.4 (average and readily biodegradable). The BOD/COD ratio was slowly biodegradable in two months (May 2017 and Jun. 2017) and not biodegradable in two months (Apr. 2018 and Nov. 2018). However, the mean value of the BOD/COD ratio was 0.51, which shows the wastewater is generally readily biodegradable [37].

3.2 Effluent characteristics

Table 5 shows the treated water properties at the Al-Thagher WWTP. Iraqi water quality standards (IWQS) [38] are used as a basis for the water quality evaluation of the present study. The parameters for T, pH, NH_3–N, COD and BOD in the effluent (treated water) met the IWQS. The remaining parameters met the IWQS standard in some months but did not in other months. PO_4–P met IWQS in most months except Feb. 2018 to Sep. and Nov. 2018 to Dec. 2018. Cl^{-1} met IWQS in most months except Mar. 2017, Dec. 2017, Apr. 2018, Nov. 2018 and Dec. 2018. SO_4^{-2} did not meet IWQS in most months except Apr. 2017 to Aug. 2017 and Jul. 2018 to Sep. 2018. TSS met IWQS in most months except Feb. 2017 to Apr. 2017 and Dec. 2018. EC and TDS do not meet IWQS in most months except May 2017 to Aug. 2017 and Aug. 2018 to Sep. 2018.

Table 4 BOD/COD ratio and biodegradability of organic matter [1]

Ratio	Biodegradable of organic matter			
	Not	Slowly	Average	Readily
BOD/COD	< 0.2	0.2–0.4	0.4–0.5	0.5–0.8

Variation of the BOD/COD ratio in influent and effluent are shown in Fig. 3. In the first six months (Feb. 2017 to Jul. 2017), the BOD/COD ratio of effluent (0.39–0.46) is slightly higher than the BOD/COD ratio of influent (0.47–0.58), which is almost constant, so the curve is horizontal during this period. For the next month (Aug. 2017), the BOD/COD ratio of effluent (0.48) and influent (0.46) were almost identical. In the following six months, the BOD/COD ratio of effluent (0.41–0.49) was lower than the BOD/COD ratio of influent (0.53–0.84), which gradually increases. In Apr. 2018, the BOD/COD ratio of effluent (0.30) slightly increased above the BOD/COD ratio of influent (0.19). In the final months of the study period, a fluctuation occurs in the curve of BOD/COD ratio of effluent and influent, and the highest BOD/COD ratio of effluent was 1.31 in Nov. 2018.

The BOD/COD ratio naturally decreases over each stage of traditional wastewater treatment. This occurs mainly because the biodegradable fraction of organic matter, measured by the BOD, is first degraded by the present microorganisms, while the more inert fraction of organic matter is usually constant during treatment. Therefore, BOD tends to decrease faster than COD, and the BOD/COD ratio decreases. However, sometimes BOD increases during treatment because of the dissolution of organic particulate matter or hydrolysis of complex organic molecules, which cause an increase in the COD. This phenomenon depends on many factors, such as the composition of the wastewater, biomass acclimation to wastewater, presence of inhibitors (like ammonia) and more. When it happens, BOD/COD ratio will increase [39].

3.3 Water quality index (CCME WQI)

It is necessary to represent the effluent quality by a single WQI number because some parameters were met, and other parameters did not meet the IWQS, as shown in Section 3.2.

Table 5 Effluent wastewater characteristics of the Al-Thagher WWTP by month

Month	T	pH	EC	TDS	TSS	SO_4^{-2}	Cl^{-1}	NH_3–N	PO_4–P	COD	BOD	BOD/COD
Feb-17	16.3±2.9	6.7±0.15	3178±432	1598±315	89±19	456±132	562±69	5.4±1.0	1.2±0.9	28±10	15±6	0.46
Mar-17	21.7±3.8	7.0±0.05	3437±510	2000±218	93±13	495±107	630±103	0.6±0.3	1.0±0.4	70±15	33±6	0.41
Apr-17	25.9±5.3	7.1±0.11	2566±513	1507±231	72±11	371±79	452±85	4.2±1.2	0.5±0.2	69±12	32±4	0.4
May-17	29.6±5.4	7.2±0.22	1694±652	1014±332	41±15	247±111	273±86	7.8±1.0	0.2±0.1	64±10	31±5	0.39
Jun-17	34.8±5.3	7.1±0.08	1773±362	1072±217	21±14	252±112	298±74	7.4±1.5	1.6±0.8	39±10	19±4	0.39
Jul-17	37.9±4.0	7.0±0.10	1940±608	1208±345	11±5	265±101	322±67	7.0±1.1	2.9±1.4	16±11	10±4	0.41
Aug-17	35.5±4.1	7.1±0.14	2131±471	1416±377	12±5	331±134	291±105	7.2±1.5	1.8±1.2	23±12	11±4	0.46
Sep-17	31.2±3.5	7.3±0.07	2405±372	1646±380	15±10	416±83	260±111	7.6±1.1	0.7±0.5	29±8	12±4	0.53
Oct-17	25.8±4.9	7.3±0.24	2955±511	1869±410	22±15	462±71	362±97	7.9±1.1	0.7±0.5	26±11	11±4	0.61
Nov-17	20.0±4.1	7.3±0.19	3615±543	2074±346	32±17	490±124	553±80	8.1±1.4	0.7±0.4	20±10	8±4	0.65
Dec-17	17.2±5.4	7.3±0.23	3936±408	2164±264	37±11	516±76	655±120	8.2±1.2	0.7±0.5	17±13	7±3	0.66
Jan-18	17.7±4.2	7.2±0.23	3658±431	2085±412	32±18	548±118	596±78	7.6±1.5	3.1±1.4	28±8	13±6	0.72
Feb-18	19.3±5.2	7.1±0.19	3142±559	1939±369	22±11	577±87	486±111	6.4±1.6	7.6±2.9	48±11	23±6	0.84
Mar-18	22.0±4.7	7.0±0.10	2864±544	1860±375	17±8	590±113	428±70	5.3±0.9	10.0±2.6	59±9	29±6	0.81
Apr-18	26.6±3.9	7.1±0.24	3388±446	2234±281	47±19	539±132	645±107	4.5±1.4	7.8±2.1	50±14	15±6	0.19
May-18	26.2±5.2	7.2±0.07	2600±359	1712±283	48±19	462±128	478±108	6.1±1.3	9.9±2.8	66±13	12±4	0.4
Jun-18	32.7±2.9	7.3±0.08	2476±507	1556±377	52±19	427±127	445±84	7.6±1.0	9.9±1.7	60±12	28±6	0.55
Jul-18	31.7±4.0	7.2±0.04	2571±452	1750±396	18±9	392±134	421±87	6.8±1.1	8.7±1.7	30±8	22±4	0.58
Aug-18	33.8±4.2	7.4±0.15	2311±528	1218±267	44±12	322±81	410±65	5.9±1.6	7.1±3.1	36±9	20±4	0.61
Sep-18	30.9±3.5	6.2±0.18	1851±547	1146±249	11±7	310±72	314±89	3.8±1.4	7.1±2.4	18±8	11±4	0.46
Oct-18	23.9±3.4	7.0±0.23	2553±652	1560±287	45±14	435±115	562±74	1.3±0.9	0.1±0.1	49±14	20±4	0.43
Nov-18	19.6±2.8	7.3±0.05	4427±517	3126±246	50±19	954±85	780±75	4.2±1.5	7.1±2.9	15±7	20±6	0.19
Dec-18	15.6±3.4	7.2±0.05	4680±434	2764±234	61±15	837±131	801±103	3.8±1.2	10.8±2.4	50±10	20±5	0.51
Ave.	25.9	7.1	2876	1762	39	465	479	5.9	4.4	40	18	0.50
SD (±)	6.8	0.3	822	517	24	170	157	2.1	3.9	19	8	0.21
Max	37.9	7.4	4680	3126	93	954	801	8.2	10.8	70	33	1.31
Min	15.6	6.2	1694	1014	11	247	260	0.6	0.1	15	7	0.18
IWQS	16–32	6–9	2500	1500	60	400	600	10	5	100	40	

Note: 1) All values (mean ± SD) are expressed in mg/L (ppm) except pH (dimensionless), EC (µs/cm) and temperature (°C). 2) Shaded values in grey are indicted that these values did not meet IWQS

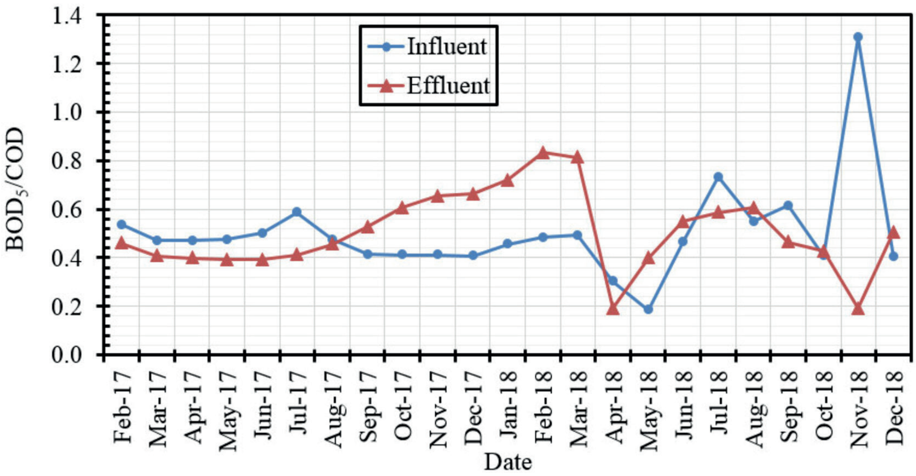

Fig. 3 Variation of BOD/COD ratio in influent and effluent

The CCME WQI is the most reliable and adaptable in terms of the form and amount of water quality variables to be evaluated, the time of application, the accuracy of the selection criterion, the tolerance for incomplete tests, and the kind of aquatic ecosystem [17, 19]. Therefore, CCME WQI was used in this study to evaluate the water quality of effluent. The CCME WQI mathematical formula is shown below [17, 19].

$$CCME\ WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \quad (1)$$

The CCME WQI is based on selecting parameters and setting objectives for each parameter. The index calculates three factors based on these objectives: the scope factor (F_1) represents the number of parameters that fail their objective during the index period (Eq. (2)), the frequency factor (F_2) represents the proportion of samples that fail their objectives during the index period (Eq. (3)), and the amplitude factor (F_3) represents the relative magnitude of any failures during the index period (Eqs. (4) and (5)). Thus two important environmental aspects, the frequency and severity of adverse conditions, are included in the calculation of the CCME WQI [19].

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}} \right) \times 100 \quad (2)$$

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}} \right) \times 100 \quad (3)$$

$$nse = \frac{\sum_{i=1}^{n} \left(\frac{\text{Failed Test Value}_i}{\text{Objective}_i} \right) - 1}{\text{Number of Test}} \quad (4)$$

$$F_3 = \left(\frac{nse}{0.01 nse + 0.01} \right) \quad (5)$$

The CCME WQI calculations were conducted using CCME WQI calculator 2.0 software. This software has been downloaded from the website for the Canadian Council for Ministers of the Environment. The calculated value of CCME WQI is presented in Table 6 [19].

The effluent parameters of the Al-Thagher WWTP between February 2017 and December 2018 were used to determine the effluent CCME WQI. The following parameters were used to calculate the index: pH, EC, TDS, TSS, Cl^{-1}, SO_4^{-2}, NH_3–N, COD, BOD, Temp., and PO_4–P. The water quality parameters were determined according to the IQWS, which is listed in the last row in Table 5. The calculation details of CCME WQI are presented in Table 7. The estimated CCME WQI value was 51.8. The water quality was graded as "Marginal", which means the water quality of the effluent was frequently threatened and impaired, and conditions often depart from natural levels.

3.4 Wastewater treatment performance

The influent and effluent characteristics of the Al-Thagher WWTP are illustrated graphically in Fig. 4. Concentrations of COD, BOD, TSS and NH_3–N in the effluent during all the studied months are less than their concentration in influent, as shown in Figs. 4(a), 4(b), 4(c), and 4(d), respectively. The concentrations of the remaining parameters (PO_4–P, Cl^{-1}, EC, TDS, SO_4^{-2}, and pH) in effluent fluctuated above and below the influent concentration, as shown in Figs. 4(e), 4(f), 4(g), 4(h), 4(i), and 4(j), respectively.

Table 6 Classification of CCME WQI values [19]

CCME WQI	Ranks	Water Quality Characteristics
95-100	Excellent	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.
80-94	Good	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
65-79	Fair	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
45-64	Marginal	water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
0-44	Poor	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

Table 7 Details of CCME WQI calculations for effluent quality of the Al-Thagher WWTP

Item	Value
Total No. of parameters	11
Total No. of tests	253
No. of failed parameters	8
No. of failed tests	91
nse	0.24
F_1	72.73
F_2	35.97
F_3	19.68
CCME WQI	51.80

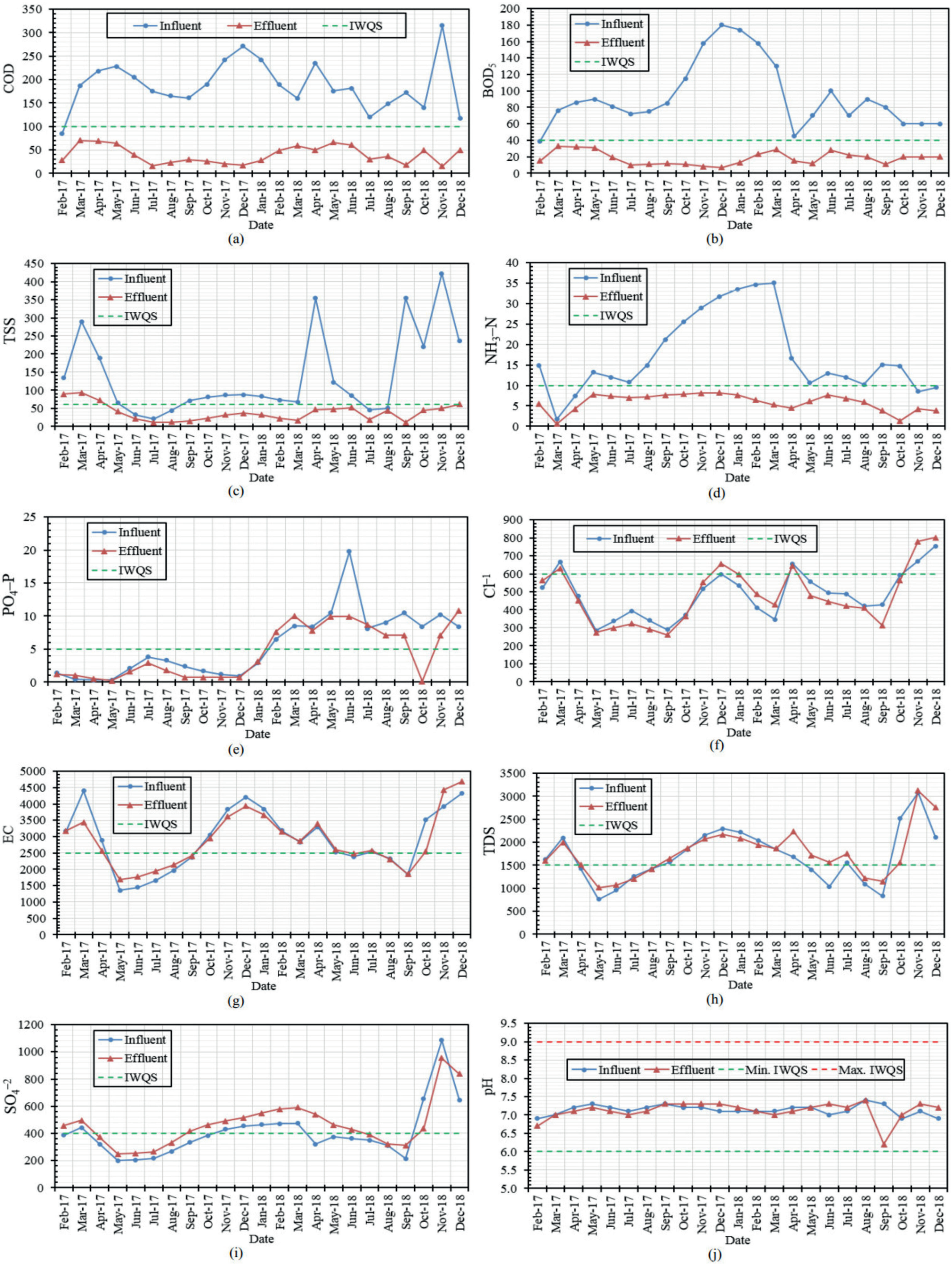

Fig. 4 Influent and effluent characteristics of the Al-Thagher WWTP. (a) COD, (b) BOD, (c) TSS, (d) NH_3–N, (e) PO_4–P, (f) Cl^{-1}, (g) EC, (h) TDS, (i) SO_4^{-2} and (j) pH

Table 8 lists the removal efficiency of the main parameters for the Al-Thagher WWTP. In Table 8, the positive sign indicates that pollutant removal is efficient. The negative sign indicates that there is no efficiency of pollutant removal or there is an increase in the concentration of the pollutant in the effluent of the plant. PO_4–P removals in 16 months were positive and negative in the other seven months. The positive removal of PO_4–P were ranged from 5.71 to 98.81%. Cl^{-1} removals in 15 months were positive and negative in the other eight months. The positive removal of Cl^{-1} ranged from 1.68 to 26.64%. EC removal was negative in 14 months and positive in the other nine months. The positive removal of EC ranged from 0.73 to 27.47%. TDS removal was negative in 15 months and positive in the other eight months. The positive removal of TDS was ranged from 1.72 to 38.1%. SO_4^{-2} removal was negative in 21 months and positive in the other two months. The positive removal of SO_4^{-2} ranged from 12.07 to 33.59%.

The average removal efficiencies of some parameters (COD, BOD, TSS, and NH_3–N) were greater than 50%, and other parameters (PO_4–P, Cl^{-1}, EC, TDS, and SO_4^{-2}) had removal efficiencies less than 50%. Therefore, the plant was efficient for removing COD, BOD, TSS, and NH_3–N and not efficient for removing PO_4–P, Cl^{-1}, EC, TDS, and SO_4^{-2}.

3.5 T-test of removal efficiency

The summary of the Al-Thagher WWTP performance in terms of the t-test and removal efficiency is listed in Table 9 and shown in Fig. 5. In general, there is a significant removal efficiency when the t-test result is less than or equal to 0.05 ($t \leq 0.05$), and vice versa. The results show a significant removal efficiency ($t < 0.05$) of BOD, COD, NH_3–N and TSS; these parameters had high removal percentages compared to other parameters. In contrast, there are low or negative removal efficiencies for PO_4–P, SO_4^{-2}, TDS, EC, and Cl^{-1}, and the t-test results show no significant difference

Table 8 Monthly average removal efficiency of the main parameters for the effluent of the Al-Thagher WWTP

Month	Removal (%)								
	COD	BOD	TSS	NH_3–N	PO_4–P	Cl^{-1}	EC	TDS	SO_4^{-2}
Feb-17	67.06	61.54	33.58	63.76	14.29	–7.46	–0.38	1.72	–18.13
Mar-17	62.57	56.58	67.93	64.71	–150.00	5.55	21.82	4.58	–12.24
Apr-17	68.35	62.79	61.90	43.24	–66.67	4.84	10.87	–5.68	–15.94
May-17	71.93	65.56	36.92	40.91	33.33	3.87	–24.38	–34.13	–24.12
Jun-17	80.98	76.54	34.38	38.33	23.81	11.83	–22.53	–12.02	–23.53
Jul-17	90.86	86.11	47.62	35.19	23.68	18.07	–17.01	4.13	–22.12
Aug-17	86.06	85.33	72.73	51.68	45.45	14.66	–8.50	0.00	–23.97
Sep-17	81.99	85.88	78.87	64.15	70.83	10.34	–1.35	–5.11	–24.92
Oct-17	86.32	90.43	72.84	69.02	58.82	2.16	3.18	–1.58	–20.31
Nov-17	91.74	94.94	63.22	72.07	41.67	–6.76	5.64	3.53	–14.22
Dec-17	93.73	96.11	57.95	74.13	22.22	–9.53	6.37	5.83	–13.41
Jan-18	88.43	92.53	61.45	77.31	-6.90	–11.82	4.94	6.08	–17.85
Feb-18	74.60	85.44	69.86	81.50	–16.92	–17.96	1.44	5.09	–22.51
Mar-18	63.13	77.69	75.00	84.86	–17.65	–23.34	–1.13	-0.43	–24.74
Apr-18	78.72	66.67	86.72	72.89	7.14	1.68	–2.60	–33.29	–68.44
May-18	62.50	82.86	60.66	42.45	5.71	13.87	–2.89	–22.11	–23.20
Jun-18	66.85	72.00	38.82	41.54	50.00	9.92	–3.60	–50.19	–17.63
Jul-18	75.00	68.57	60.87	43.33	-7.41	13.91	–1.34	–12.32	–12.00
Aug-18	75.68	77.78	12.00	42.16	21.11	2.61	0.73	–11.54	–3.21
Sep-18	89.53	86.25	96.89	74.83	32.38	26.64	–0.22	–38.07	–45.54
Oct-18	65.00	66.67	79.55	91.16	98.81	4.91	27.47	38.10	33.59
Nov-18	95.24	66.67	88.15	50.59	30.39	–16.42	–12.82	–1.82	12.07
Dec-18	57.63	66.67	74.15	60.00	–28.57	–6.37	–8.33	–31.12	–29.77
Max.	95.24	96.11	96.89	91.16	98.81	26.64	27.47	38.10	33.59
Min.	57.63	56.58	12.00	35.19	–150.00	–23.34	–24.38	–50.19	–68.44
Average	77.12	77.03	62.26	59.99	12.42	1.97	–1.07	–8.28	–18.79
SD (±)	11.61	11.76	20.47	16.99	49.95	12.63	11.99	19.33	18.57

Table 9 Minimum, maximum, average, standard deviation (SD) and t-test for the removal rate efficiency of the Al-Thagher WWTP

Parameter	Removal Efficiency %				t-test
	Average	Max.	Min.	SD (±)	
COD	77.12	95.24	57.63	11.61	0.437×10^{-12}
BOD	77.03	96.11	56.58	11.76	0.595×10^{-8}
NH_3–N	59.99	91.16	35.19	16.99	0.109×10^{-4}
TSS	62.26	96.89	12.00	20.47	0.447×10^{-3}
SO_4^{-2}	−18.79	33.59	−68.44	18.57	0.284
PO_4–P	12.42	98.81	−150.00	49.95	0.359
TDS	−8.28	38.10	−50.19	19.33	0.646
EC	−1.07	27.47	−24.38	11.99	0.900
Cl^{-1}	1.97	26.64	−23.34	12.63	0.902

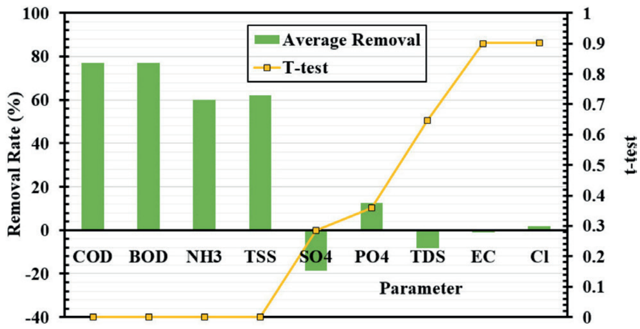

Fig. 5 Average and t-test for the removal rate efficiency of the Al-Thagher WWTP

in efficiency ($t > 0.05$). However, there is no removal efficiency for these parameters, but increasing their concentrations in the effluent was due to the mixing of influent with the previous higher concentration wastewater remaining in the aeration tank or settling tank.

The results indicate that the wastewater treatment is failing. These factors include the consistency of the return activated sludge (RAS) or inadequate aeration, which prevents microorganisms from biodegrading organic matter. In addition, the secondary sedimentation tank cannot work efficiently because it does not have enough time to settle sludge. As a result, the sewage treatment process needs to be operationally improved. In general, surface water bodies are in grave danger due to indiscriminate discharge of contaminated effluents from inefficient treatment and sewage activities.

3.6 Correlation and linear regression

Knowing the correlation between sewage treatment parameters can facilitate rapid monitoring of the sewage treatment process. The correlation coefficient (R) was used to explain the type of relationship (positive or negative) between each two of the studied parameters. The coefficient of determination (R^2) was used to determine the strength of the relationship between each two of the studied parameters, as shown in Table 10. Linear regression equations for very strong, strong, and moderate correlations between the studied parameters were established. The linear regression equations between parameters are very important, especially those between a parameter that requires a long measuring time and another parameter that requires a shorter time and less effort. If the relationship between the two is known, then the parameter that requires less effort can be tracked, and the status of the parameter that requires more time can be predicted with reasonable accuracy.

The determination coefficients (R^2) of the studied parameters for influent wastewater are shown in Table 11. TDS has a strong correlation with SO_4^{-2} ($R^2 = 0.76$) and

Table 10 Strength of association correlation according to the value of R^2

value	Value of R^2	Strength of association
$0 \le R^2 < 0.25$	0.00 – 0.24	No correlation
$0.25 \le R^2 < 0.50$	0.25 – 0.49	Weak correlation
$0.50 \le R^2 < 0.75$	0.50 – 0.74	Moderate correlation
$0.75 \le R^2 < 0.90$	0.75 – 0.89	Strong correlation
$0.90 \le R^2 < 1$	0.90 – 0.99	Very strong correlation
$R^2 = 1$	1.00	Perfect correlation

Table 11 Determination coefficient (R^2) among the parameters of influent wastewater

	COD	BOD	SO_4^{-2}	Cl^{-1}	TDS	TSS	EC	NH_3–N	PO_4–P
COD	1.00	0.18	0.09	0.02	0.11	0.12	0.05	0.04	0.02
BOD		1.00	0.00	0.03	0.05	0.13	0.07	0.67	0.05
SO_4^{-2}			1.00	0.39	0.76	0.26	0.48	0.00	0.06
Cl^{-1}				1.00	0.38	0.41	0.64	0.06	0.05
TDS					1.00	0.14	0.75	0.08	0.01
TSS						1.00	0.17	0.12	0.08
EC							1.00	0.04	0.01
NH_3–N								1.00	0.02
PO_4–P									1.00

EC (R^2 = 0.75). Cl^{-1} and BOD have a moderate correlation with EC (R^2 = 0.64) and NH_3–N (R^2 = 0.67), respectively. The remaining linear relationships between parameters had a weak correlation. The intercepts (a) and slopes (b) of the linear regression equations (Y = a + b X) for strong and moderate correlation between these parameters (X, Y) are listed in Table 12. These linear relationships all had a positive correlation (+R).

The determination coefficients (R^2) of the studied effluent parameters are shown in Table 13. The present study reveals a very strong correlation (R^2 = 0.92) for the linear relationship of SO_4^{-2} with TDS. There are strong correlations (R^2 = 0.90, 0.85, and 0.81) for the linear relationships of TDS with EC, Cl^{-1} with EC, and SO_4^{-2} with EC, respectively. There is a moderate correlation (R^2 = 0.74, 0.69, and 0.60) for the linear relationship of Cl^{-1} with TDS, Cl^{-1} with SO_4^{-2}, and BOD with COD, respectively. The remaining linear relationships between other parameters had a weak correlation. The intercepts (a) and slopes (b) of the linear regression equations (Y = a + b X) for strong and moderate correlations between these parameters (X, Y) are listed in Table 14. These linear relationships all had a positive correlation (+R).

Table 12 Linear regression equations for strong and moderate correlation among the parameters of influent wastewater

Influent (Y)	Influent (X)	R	R^2	Evaluation	Linear Regression equation Y = a + b X	
					Intercept (a)	Slope (b)
SO_4^{-2}	TDS	0.87	0.76	Strong Correlation	–79.95	0.29
TDS	EC	0.86	0.75	Strong Correlation	119.53	0.54
Cl^{-1}	EC	0.80	0.64	Moderate correlation	153.77	0.11
BOD	NH_3–N	0.82	0.67	Moderate correlation	35.04	3.41

The determination coefficients (R^2) between the studied parameters of influent and effluent are shown in Table 15. SO_4^{-2} in the effluent has a strong correlation with SO_4^{-2} (R^2 = 0.79) in the influent, and it has a moderate correlation with Cl^{-1} (R^2 = 0.58), TDS (R^2 = 0.69), and EC (R^2 = 0.57) in the influent. Cl^{-1} in the effluent has a strong correlation with Cl^{-1} (R^2 = 0.87) in the influent, and it has a moderate correlation with TDS (R^2 = 0.54) and EC (R^2 = 0.61) in the influent. TDS in the effluent has a moderate correlation with TDS (R^2 = 0.70), EC (R^2 = 0.68), SO_4^{-2} (R^2 = 0.64), and Cl^{-1} (R^2 = 0.58) in the influent. EC in the effluent has a strong correlation with EC (R^2 = 0.85) and Cl^{-1} (R^2 = 0.80) in the influent, and it has a moderate correlation with TDS (R^2 = 0.69) and SO_4^{-2} (R^2 = 0.58) in the influent. TSS in the effluent has a moderate correlation with NH_3–N (R^2 = 0.50) and PO_4^{-2} (R^2 = 0.52) in the influent. PO_4–P in the effluent has a moderate correlation with PO_4–P (R^2 = 0.66) in the influent. The remaining linear relationships between other parameters had a weak correlation. The intercepts (a) and slopes (b) of the linear regression equations (Y = a + b X) for strong and moderate correlations between these parameters (X, Y) are listed in Table 16. These linear relationships all have a positive correlation (+R), except the relationship of TSS with NH_3–N is negative (–R).

4 Conclusions

The following significant conclusions can be drawn from the present evaluation of the Al-Thagher WWTP.

- The effluent (treated water) of the Al-Thagher WWTP met Iraqi water quality standards in some parameters (T, pH, NH_3–N, COD and BOD), while standards for other parameters (EC, TDS, TSS, SO_4^{-2}, Cl^{-1} and PO_4–P) have not been met.
- The CCME WQI value of treated water was 51.80 and classified as "marginal", which means the water

Table 13 Determination coefficient (R^2) among the parameters of effluent wastewater

	COD	BOD	SO_4^{-2}	Cl^{-1}	TDS	TSS	EC	NH_3–N	PO_4–P
COD	1.00	0.60	0.00	0.00	0.01	0.25	0.01	0.15	0.04
BOD		1.00	0.00	0.00	0.00	0.21	0.01	0.18	0.03
SO_4^{-2}			1.00	0.69	0.92	0.08	0.81	0.08	0.17
Cl^{-1}				1.00	0.74	0.34	0.85	0.19	0.06
TDS					1.00	0.08	0.90	0.05	0.09
TSS						1.00	0.17	0.30	0.01
EC							1.00	0.04	0.04
NH_3–N								1.00	0.01
PO_4–P									1.00

quality of effluent was frequently under threat and degraded and was often not in the desired conditions.

- The average removal efficiency of the parameters in sorted descending order is COD (77.12%) > BOD (77.03%) > TSS (62.26%) > NH_3–N (59.99%) > PO_4–P (12.42%) > Cl^{-1} (1.97%). Meanwhile, the EC, TDS, and SO_4^{-2} parameters achieved negative average removal efficiency.
- In the influent, the determination coefficients (R^2) described a strong correlation for the linear relationships of SO_4^{-2} with TDS and TDS with EC. There is a moderate correlation for the linear relationships of Cl^{-1} with EC and BOD with NH_3–N.
- In the effluent, the determination coefficients (R^2) described a strong correlation for the linear relationships of SO_4^{-2} with EC, Cl^{-1} with EC and TDS with EC. There is a very strong correlation for a linear relationship of SO_4^{-2} with TDS and a moderate correlation for the linear relationships of BOD with COD and Cl^{-1} with SO_4^{-2}.
- The determination coefficients (R^2) of each effluent-influent parameter pair varied between strong and moderate correlation. Cl^{-1} in effluent has a strong correlation with the Cl^{-1} in influent. It has a moderate correlation with TDS and EC in influent. SO_4^{-2} in effluent has a strong correlation with SO_4^{-2} in influent but a moderate correlation with TDS, EC, and Cl^{-1} in influent. EC of effluent has a strong correlation with EC and Cl^{-1} of influent and a moderate correlation with TDS of influent. TDS, TSS, and PO_4–P of effluent have a moderate correlation with TDS, TSS, and PO_4–P of influent, respectively.

Prediction of effluent quality based on the input variables would be very useful in ongoing operations. These relationships support measuring some parameters and calculating others using these equations. Using these equations will save the time, effort and money that can be used to conduct additional laboratory measurements. Furthermore, the efficiency gained from the use of these equations can be invested in future studies that introduce more operational parameter data, such as total nitrogen (TN), total phosphate (TP), and COD fractionation, for a longer time, using years of data for calibration and validation. Other techniques such as artificial neural networks and genetic algorithms might also be introduced.

Table 14 Linear regression equations for strong and moderate correlation among the parameters of effluent wastewater

Effluent (Y)	Effluent (X)	R	R^2	Evaluation	Linear Regression equation Y = a + b X	
					Intercept (a)	Slope (b)
BOD	COD	0.77	0.60	Moderate correlation	5.13	0.33
Cl^{-1}	SO_4^{-2}	0.83	0.69	Moderate correlation	121.28	0.77
SO_4^{-2}	TDS	0.96	0.92	Very strong correlation	−90.07	0.32
Cl^{-1}	TDS	0.86	0.74	Moderate correlation	17.73	0.26
SO_4^{-2}	EC	0.90	0.81	Strong Correlation	−70.84	0.19
Cl^{-1}	EC	0.92	0.85	Strong Correlation	−28.69	0.18
TDS	EC	0.95	0.90	Strong Correlation	43.76	0.60

Acknowledgment

Thanks and gratitude to the Iraqi Ministry of Municipalities and Basrah Sewerage Directorate for providing all measurements used in this study.

Table 15 Determination coefficient (R^2) among the parameters of influent and effluent wastewater

Influent Parameters	Effluent Parameters: COD	BOD	SO_4^{-2}	Cl^{-1}	TDS	TSS	EC	NH_3–N	PO_4–P
COD	0.02	0.01	0.08	0.07	0.14	0.00	0.09	0.04	0.00
BOD	0.03	0.03	0.00	0.00	0.01	0.10	0.04	0.25	0.11
SO_4^{-2}	0.01	0.01	0.79	0.58	0.69	0.08	0.57	0.15	0.02
Cl^{-1}	0.01	0.00	0.46	0.87	0.54	0.38	0.61	0.31	0.03
TDS	0.04	0.01	0.64	0.59	0.70	0.05	0.68	0.10	0.01
TSS	0.01	0.02	0.27	0.30	0.26	0.11	0.17	0.50	0.02
EC	0.00	0.00	0.58	0.80	0.69	0.25	0.85	0.15	0.02
NH_3–N	0.08	0.11	0.02	0.00	0.02	0.22	0.04	0.24	0.18
PO_4–P	0.06	0.03	0.01	0.03	0.00	0.00	0.00	0.10	0.12

Table 16 Linear regression equations for strong and moderate correlation among the parameters of influent and effluent wastewater

Effluent (Y)	Influent (X)	R	R^2	Evaluation	Linear Regression equation Y = a + b X	
					Intercept (a)	Slope (b)
SO_4^{-2}	SO_4^{-2}	0.89	0.79	Strong Correlation	–58.57	1.00
SO_4^{-2}	Cl^{-1}	0.76	0.58	Moderate correlation	–36.50	0.93
SO_4^{-2}	TDS	0.83	0.69	Moderate correlation	–133.55	0.31
SO_4^{-2}	EC	0.75	0.57	Moderate correlation	–97.79	0.18
Cl^{-1}	Cl^{-1}	0.93	0.87	Strong Correlation	112.46	0.78
Cl^{-1}	TDS	0.73	0.54	Moderate correlation	158.08	0.19
Cl^{-1}	EC	0.78	0.61	Moderate correlation	126.41	0.12
TDS	TDS	0.84	0.70	Moderate correlation	37.88	0.94
TDS	EC	0.82	0.68	Moderate correlation	23.61	0.58
TDS	SO_4^{-2}	0.80	0.64	Moderate correlation	423.00	2.72
TDS	Cl^{-1}	0.77	0.59	Moderate correlation	330.38	2.83
EC	EC	0.92	0.85	Strong Correlation	–60.21	1.03
EC	TDS	0.83	0.69	Moderate correlation	306.57	1.48
EC	SO_4^{-2}	0.76	0.58	Moderate correlation	999.60	4.11
EC	Cl–1	0.89	0.80	Strong Correlation	406.10	5.22
TSS	NH_3–N	–0.71	0.50	Moderate correlation	365.54	–39.30
PO_4–P	PO_4–P	0.81	0.66	Moderate correlation	1.20	1.00

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