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The Evaluation of Biological Treatment of Wastewater in the Yarmouk Station and Its Suitability for Aquaculture and Irrigation in Mosul City, Iraq

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ABSTRACT

The study aimed to assess the performance of Yarmouk station for treating sewage water in Mosul City, Ninevah province. The station's performance was estimated based on the analysis of water quality data, including measurements of TSS, TDS, EC, pH, temperature, turbidity, TH, ALK, SO_4^{2-}, Mg^{2+}, Ca^{2+}, K^+, Na^+, HCO_3^-, Cl^-, and NO^{3-}. Additionally, the biological oxygen demand (BOD) and chemical oxygen demand (COD) of the station were measured. The study results showed that the station's water matched the standard specifications for water quality, and the treated water met the WQI water quality standards. The efficiency of treatment stations is generally measured by their ability to remove organic matter, which can be elucidated through the amount of BOD and TSS removed. The station's efficiency in removing BOD was found to be 82.8%, and the removal efficiency for TSS was 85.2%. The results also indicated that the water discharged from the station is suitable for irrigation according to *KR* and *SAR* values and within irrigation guidelines. Overall, the station was found to operate efficiently within the Iraqi discharge standards.

INTRODUCTION

Effective sewage treatment is perhaps the truest sign of civilization and culture **(Sastry, 1995)**. Sewage water originates from residential, commercial, and industrial activities **(Metcalf *et al*., 2014)**. Typically, sewage water is contaminated with physical, chemical, and biological compounds that have a significant negative impact on the environment **(Tee *et al*., 2016)**. Discharging sewage water into rivers without treatment or with ineffective treatment by treatment plants causes serious damage to aquatic environments due to the high concentrations of pollutants in these waters **(Salem *et al*., 2008)**. Surface water in developing countries is at a significant risk due to the massive discharge of contaminated sewage water **(Kambole, 2003)**. Given the characteristics of raw sewage water and the requirements for its disposal or reuse, sewage water usually requires some form of treatment before it becomes suitable for disposal or reuse **(Kumar *et al*., 2010)**. Sewage water treatment includes three stages: primary, secondary, and tertiary treatment. The degree of reduction in biological oxygen demand (BOD) and total suspended solids (TSS) is a general measure of the efficiency of sewage treatment plants **(Friedler & Pisanty, 2006)**. Sewage treatment plants are designed and operated to encourage natural treatment processes to reduce pollutant loads to levels that nature can manage **(APHA & APHA-AWWA, 2005)**. The required level of treatment depends on regulatory standards and criteria for discharge, which typically include goals such as protecting water sources from pollution, preventing the spread of diseases, reducing sedimentation in surface water bodies, eliminating damage associated with sewage water, and addressing odor problems **(Jamrah, 1999)**. The efficiency of treatment plants is generally measured by their ability to remove organic matter. Both BOD and TSS are considered key indicators of treatment efficiency **(Culp & Culp, 1971)**.

1. Site study

Yarmouk treatment station is located on the right side of Mosul City at coordinates 36.331860, 43.082413, as shown in Fig. (1), covering an area of 4 dunums (10,000m^2). The station was established in 2007 and serves a population of 50,000. It treats sewage water from Yarmouk apartment area and two streets from the Nablus area. The treated water is discharged into a valley next to the station, which flows into the Tigris River. The station operates on an activated sludge system (enhanced aeration system), known for its high efficiency in removing TSS, BOD, and COD, producing high-quality effluent according to standards. The station consists of the following parts:

1.1 Lifting basin

A 1.20-meter diameter pipe (the conveyor pipe from the apartments) enters the basin, followed by a mechanical strainer that removes suspended and floating materials. At the top of the basin, there are three lift pumps that lift the wastewater into the equalization basin. The capacity of each pump is 37 kilowatts, discharging 500 cubic meters per hour. Next to the pump is a water-preventing valve and a lock for maintenance.

1.2 Equalization basin

It is a circular basin with a diameter of 10 meters and a height of 3.60 meters with a volume of 282.6 cubic meters. The basin includes a mixer that mixes the water to obtain a homogeneous entry of wastewater into the next basin as well as to prevent the sedimentation of materials inside the basin.

1.3 Filter building

It is a building that contains a mechanical strainer that works to remove suspended materials transferred to a mechanical belt that works to transfer the removed materials to a mechanical press which compresses the materials and then throws them into a waste container. Next to the strainer is a mechanical grinder (which works in both directions, right and left), which grinds up suspended materials if they pass through the strainer.

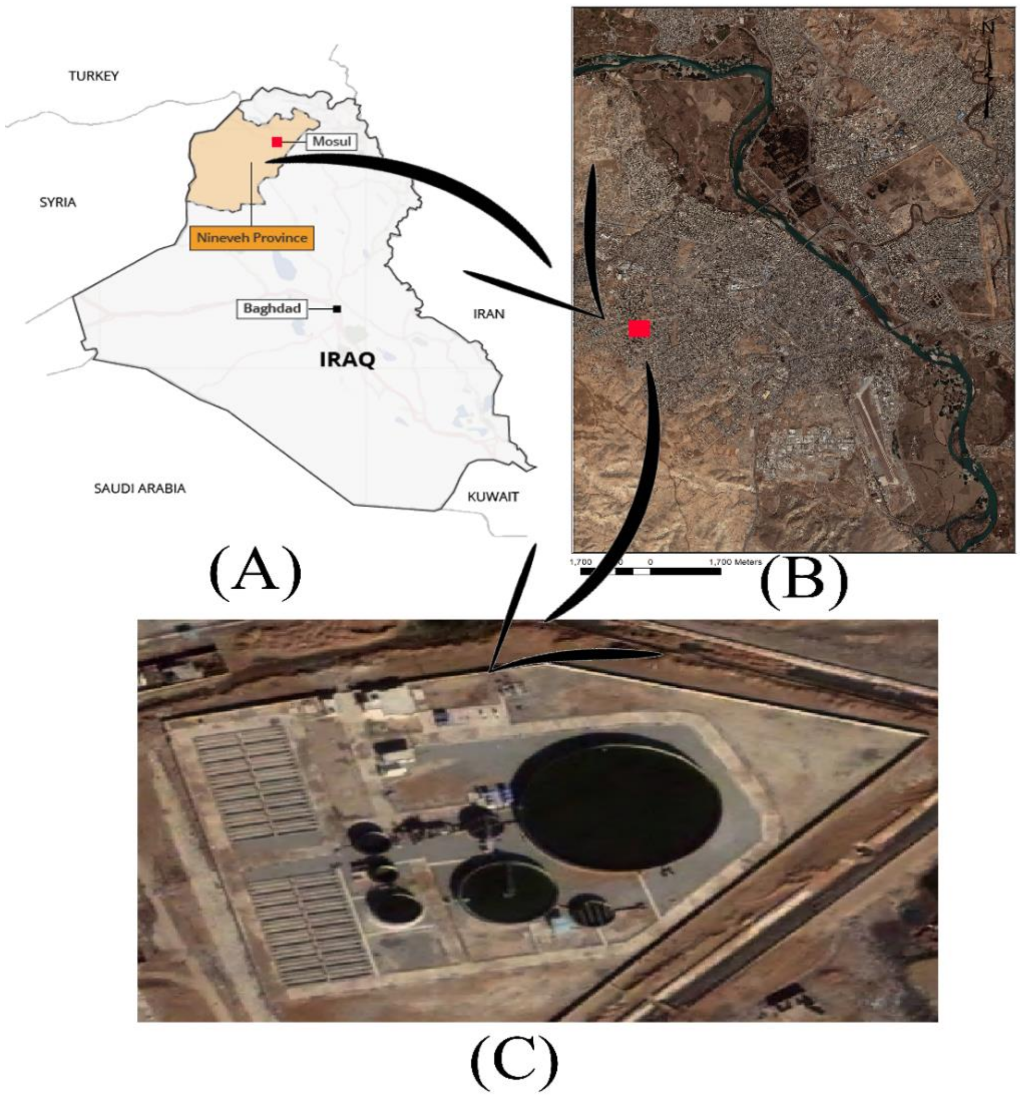

Fig. 1. Illustrates the study area: **A.** Map of Iraq, **B.** Map of Mosul City, and **C.** Yarmouk wastewater treatment plant

1.4 Sand and fat removal basin

It is a conical basin with a diameter of 10 meters and a depth of 8 meters. At the top of the basin, there is a mechanical skimmer that works to skim (remove) the fat and transfer it to a container. At the bottom of the lower basin, the sand removal process takes place through two tubes, one of which is 2 inches in diameter, through which air is pumped to the bottom of the basin, while the second tube is through which the sand is removed. A screw conveyor separates the water from the sand and the sand goes into a waste container.

1.5 Aeration basin

It is a circular basin with a diameter of 58 meters, a depth of 3.6 meters, and a volume of 9506.66 cubic meters. Through this basin, suspended and dissolved organic materials are removed and transformed into materials that can be settled by activating bacteria and living microorganisms through the introduction of air (oxygen), i.e. using activated sludge. Oxygen is entered into the aquarium using two tubes at the bottom of the aquarium. Each tube contains 450 air diffusers, meaning that the aquarium contains 900 diffusers, as the air works to stir up the water and mix it inside the aquarium. Additionally, air is supplied through 6 air compressors working alternately.

1.6 Sedimentation basin

It is a circular basin with a diameter of 28 meters and a depth of 3.5 meters. It contains a hopper at the bottom and two skimmers, one of which at the bottom works to skim the sedimented materials, so the sedimented materials go to the sludge collection basin and are used to supply the aeration basin with sludge if it is needed through a line. It is returned to the aeration basin, while the excess goes to the thickening basin, which consists of layers of coarse aggregate 3 meters high, where it is thickened by spreading it, separating the water by filtration, and returning it from the bottom to the equalization basin. The skimmer at the top works to scrape off algae or water lentils if they form and throw them into the container for disposal.

1.7 Chlorination tank

It is a tank through which chlorine is added to the water to form hypochlorous acid. The benefits of chlorination include strong oxidation, controlling taste and odor, preventing algae growth, removing iron and manganese, and sterilizing water. The water is then released into a valley near the station and in turn into the Tigris River.

The study aimed to evaluate the performance efficiency of Yarmouk sewage treatment plant and the suitability of the water coming out of it for irrigation. Discussing the operational problems facing the station, finding realistic solutions, and proposing other alternatives.

MATERIALS AND METHODS

Twenty samples were collected over a period of 5 months, starting from August 2023 until December 2023, with 4 samples collected each month. The samples covered four locations within the treatment station, including sites before the treatment process, at the aeration basin, and after the treatment process. The four samples were placed in 1-liter glass bottles, with each bottle labeled with a sticker indicating the station name, sample location, and collection date. The samples were transported in a refrigerated container and delivered to the laboratory within 24 hours for analysis.

1. Physical and chemical properties

Physical and chemical properties were analyzed according to standard methods of **Abawi and Hassan (1990)** and **APHA (2005)**. Field measurements included temperature (T C°), pH, electrical conductivity (EC), and total dissolved solids (TDS). Turbidity and total suspended solids (TSS) were measured in the laboratory. Parameters such as TH, SO_4^{2-}, Mg^{2+}, Ca_2^{+}, K^{+}, Na^{+}, HCO_3^{-}, Cl^{-}, NO_3^{-} were also analyzed. COD was analyzed using the COD Kite from Lovibond, while BOD was analyzed using the BOD-System OxiDirect from the same company. Excel and ARCMAP software were used for analysis. The analyses were conducted in the laboratories of the Dams and Water Resources Research Center and the College of Environmental Sciences at the University of Mosul.

2. Water quality index (*WQI*)

It is a means of integrating complex water quality data into a single value. The water quality index (*WQI*) is used to assess water quality and is one of the best and most widely used models globally since it focuses on influential elements (NO_3^-, K^+, SO_4^{2-}, HCO_3^-, Na^+, Mg^{2+}, Ca^{2+}, pH, TDS, TSS, BOD, COD, EC, Cl^-). The water quality index (*WQI*) was developed using the following equations as shown below **(Ebenezer *et al*., 2022)**:

$$Wi = K/VS$$

$$Qi = (Vm - Vi/Vs - VI) * 100$$

$$WQI = \sum Qi * Wi/\sum Wi$$

Qi = The quality index of the element for the total quality of the elements in the water.
Vm = The measured value of water samples.
Vi = The ideal value for water quality parameters can be obtained from standard tables; the ideal value equals zero for most parameters, except for pH = 7.
Vs = Iraqi standards for discharging treated water and agricultural irrigation **(Iraq facts, 2012)** (Table 5).
Wi = The relative unit weight of element n. K =Proportionality constant with a value of 1.

3. The Kellys ratio (*KR*)

The Kellys Ratio is the ratio of sodium concentration in water to the sum of calcium and magnesium concentrations. This ratio reflects the chemical equilibrium between sodium dissolution and the conditions of calcium and magnesium dissolution. If the *KR* values in irrigation water are greater than 1, the water is unsuitable for irrigation. Conversely, if the *KR* values in irrigation water are less than 1, the water is suitable for irrigation **(Kelley, 1941; Kucuksezgin, 1996)**.

$$KR = Na^+/Ca^{2+} + Mg^{2+}$$

4. Sodium adsorption ratio (*SAR*)

SAR is the ratio of sodium adsorption by the soil. *SAR* provides a clear idea of the sodium ion's effect on water relative to calcium and magnesium ions. It is important to consider SAR in assessing water suitability for irrigation since it affects soil salinity, hardness, and permeability **(Regional Salinity Laboratory (US), 1954; RICHARDS, 1954; Turgeon, 2000; Lesch & Suarez, 2009; Hasan *et al*., 2020)**. Table (1) presents classifications for irrigation water based on *SAR* values. *SAR* is calculated using the following equation:

$$SAR = Na^{+}/\sqrt{Ca^{2+} + Mg^{2+}/2}$$

Table 1. Classification of irrigation water based on *SAR* values **(Regional Salinity Laboratory (US), 1954; Turgeon, 2000)**.

Class	*SAR*	Hazard and limitation
S1	*0-10*	No harmful effect of sodium
S2	*18-10*	An appreciable sodium hazard in fine- textured soils of high CEC but could be used on sandy soils with good permeability
S3	*26-18*	Harmful effects could be anticipated in most soils, and amendments such as gypsum would be necessary to exchange sodium ions
S4	*>26*	Generally unsatisfactory for irrigation

RESULTS AND DISCUSSION

The study examined the physical and chemical characteristics of wastewater samples entering the treatment plant, representing water before treatment and after treatment (outflow from the plant), to determine the efficiency of the plant in reducing physical and chemical pollutants and the suitability of the water discharged from the plant for irrigation.

1. The characteristics of raw wastewater (non-treatment)

According to Table (٢), the temperature of raw sewage water before treatment ranged from 27.5 to 17.7 degrees Celsius between August and December, with an average temperature of 23.12°C. Temperature fluctuations lead to increased levels of total suspended solids (TSS) and a decrease (up to 20%) in the efficiency of removal of soluble chemical oxygen demand **(Morgan-Sagastume & Allen, 2003)**.

Turbidity levels in raw sewage water ranged from 30.6 to 145 NTU, with an average of 73.3 NTU, and the raw water is classified as having weak turbidity according to Table (3). Turbidity in sewage water is caused by suspended matters, such as clay, organic and inorganic matters, colloids, and other microscopic organisms **(Kumar, 2014)**.

Table 2. Characteristics of raw sewage water (before treatment).

No.	Par.	Unit	Aug.	Sep.	Oct.	Nov.	Dec.	Min.	Max.	Avg.	Typical Co.
1	**T**	C°	26.4	24.6	27.5	19.4	17.7	17.7	27.5	23.12	-
2	**PH**	unit	6.98	6.93	6.8	6.97	6.94	6.8	6.98	6.92	-
3	**Tur.**	NTU	31	56	65	70	145	31	145	73	W
4	**COD**	mg/L	195	163	251	177	232	163	251	203.6	S-M
5	**BOD_5**	mg/L	158	128	185	142	180	128	185	158.6	M
6	**TSS**	mg/L	194	233	163	259	193	163	259	208	M-S
7	**TDS**	mg/L	424	386	408	433	416	386	433	413	M
8	**EC**	μS/cm	848	610	667	620	606	606	848	670	W-M
9	**TH**	mg/L	304	260	256	272	266	256	304	272	-
10	**Ca^{2+}**	mg/L	59	32	32	47	41	32	59	42	-
11	**Mg^{2+}**	mg/L	38	44	43	38	40	38	44	41	-
12	**Na^{+}**	mg/L	2	3	3	3	2	2	3	3	-
13	**K^{+}**	mg/L	11	10	15	12	10	10	15	11	-
14	**HCO_3^{-}**	mg/L	268	220	259	195	190	190	268	226	-
15	**Cl^{-}**	mg/L	83	75	77	71	76	71	83	76	S
16	**NO_3^{-}**	mg/L	3	2	2	1	2	1	3	2	W
17	**SO_4^{2-}**	mg/L	107	94	104	95	104	94	107	101	S-M

*Typical Co. = Typical concentration

Table 3. Typical concentration and classification of wastewater strength **(Metcalf *et al*., 2014)**

Variable	Typical concentration			
	Unit	**Strong (S)**	**Moderate (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
NO_3	mg/L	75	45	20
SO_4^{2-}	mg/L	100	50	25
Cl^{-}	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 highest concentration of total hardness was 304mg/ L, while the lowest concentration was 256mg/ L, with an average of 271.6mg/ L. Total dissolved solids (TDS) concentrations ranged from 386 to 433mg/ L; it categorized sewage water as moderately hard. Moreover, total suspended solids (TSS) ranged from 162 to 258.5mg/ L; they are categorized between moderate to high. Electrical conductivity (EC) ranged from 606 to 848µS/ cm; it is classified as weak to moderate. Additionally, the biological oxygen demand (BOD_5) concentrations ranged from 128 to 185mg/ L and is classified as moderate. Furthermore, the highest chemical oxygen demand (COD) recorded was 251mg/ L, while the lowest was 163mg/ L, classified as weak to moderate. Chloride ion (Cl^-) concentrations ranged from 70.8 to 83.23mg/ L, classified as strong. Alkalinity (ALK) concentrations ranged from 156 to 220mg/ L. Bicarbonate (HCO_3^-) concentrations ranged from 190.32 to 268.4mg/ L. Sodium ion (Na^+) concentrations ranged from 2.11 to 3.23mg/ L. Potassium ion (K^+) concentrations ranged from 9.53 to 14.68mg/ L. Calcium ion (Ca^{2+}) concentrations ranged from 32.13 to 59.44mg/ L. Magnesium ion (Mg^{2+}) concentrations ranged from 38.05 to 43.9mg/ L. Sulfate ion (SO_4^{2-}) concentrations ranged from 94.5 to 106.7mg/ L, classified as moderate to strong. Nitrate ion (NO_3^-) concentrations ranged from 1.18 to 2.78mg/ L, classified as weak.

2. Characteristics of wastewaters (after treatment)

Table (4) illustrates the physical and chemical characteristics of treated wastewater samples, where the temperature ranged between 28.9- 17.8 degrees Celsius, with an average temperature of 23°C. Turbidity values in treated sewage water ranged from 27-10 NTU, with an average of 17.5 NTU. The removal efficiency varied between 11.9 & 90.6%, with an average removal efficiency of 65.2%, as shown in Table (5).

The highest total hardness concentration was 268mg/ L, while the lowest was 252mg/ L, with an average total hardness of 258mg/ L. Moreover, the highest removal efficiency was 11.8% in August, while the lowest was 1.6% in October, with an overall removal efficiency of 4.8%.

Total dissolved solids (TDS) concentrations ranged from 322- 398mg/ L, falling within the allowed limit according to the Iraqi disposal regulations outlined in Table (6), i.e., less than 2500mg/ L. The highest removal efficiency was 16.6% in September, and the lowest was 2.5% in October, with an overall removal efficiency of 11.9%. Total suspended solids (TSS) ranged from 25- 36mg/ L, with an average concentration of 30.1mg/ L, falling below 40mg/ L, meeting the Iraqi disposal regulations. Moreover, the removal efficiency ranged between 81.8 & 89.6%, with an average removal efficiency of 85.2%. Electrical conductivity (EC) values ranged from 470- 780µS/ cm, with an average of 568.2µS/ cm, falling below 3000µS/ cm, as per the Iraqi disposal regulations. The removal efficiency varied between 4.8- 22.4%, with an average removal efficiency of 13%. Biological oxygen demand (BOD5) concentrations ranged from 18- 34mg/ L, with an average of 26.6mg/ L, falling below 40mg/ L, meeting the Iraqi disposal regulations.

Furthermore, the removal efficiency ranged between 73.4 and 87.3%, with an average removal efficiency of 82.8%.

The highest chemical oxygen demand (COD) was 70mg/ L, the lowest was 29mg/ L, with an average of 51mg/ L, falling below 100mg/ L, as per the Iraqi disposal regulations. The removal efficiency ranged between 51.1 and 87.3%, with an average removal efficiency of 82.8%. Chloride ion (Cl^-) concentrations ranged from 43.7-72.9mg/ L, with an average of 62.5mg/ L, falling below 1000mg/ L according to the Iraqi disposal regulations. The removal efficiency ranged between 2.9- 41.7%, with an average removal efficiency of 18%.

The concentration of bicarbonates (HCO_3^-) ranged between 146.4 & 161.04mg/ L, with an average of 164.94mg/ L, falling below 610mg/ L, in compliance with the Iraqi disposal regulations. The removal efficiency values ranged between 15.4- 34%, with an average of 26.3%.

Regarding sodium ions (Na^+), their concentration ranged between 2.03 & 2.68mg/ L, with an average of 2.42mg/ L, falling below 250mg/ L, as per the Iraqi disposal regulations. Furthermore, the removal efficiency ranged between 1.4 and 14.3%, with an average of 6.8%.

Table 4. Characteristics of treated wastewater (after treatment)

No.	Par.	Unit	Aug.	Sep.	Oct.	Nov.	Dec.	Min.	Max.	Avg.	(Iraq facts, 2012)
1	**T C°**	C°	28.9	26.8	27	19	17.8	17.8	28.9	23.9	-
2	**PH**	unit	7.01	6.98	6.92	6.94	6.94	6.92	7.01	6.96	6.4-8
3	**Tur.**	NTU	27	22	15	11	14	11	27	18	-
4	**COD**	mg/L	48	70	53	55	29	29	70	51	100
5	**BOD_5**	mg/L	28	34	28	18	25	18	34	27	40
6	**TSS**	mg/L	33	36	30	27	25	25	36	30	40
7	**TDS**	mg/L	390	322	398	365	347	322	398	364	2500
8	**EC**	μS/cm	780	508	635	538	470	470	780	586	3000
9	**TH**	mg/L	268	252	252	260	258	252	268	258	-
10	**Ca^{2+}**	mg/L	56	26	24	31	29	24	56	33	450
11	**Mg^{2+}**	mg/L	31	46	47	45	45	31	47	43	80
12	**Na^+**	mg/L	2	2	3	3	2	2	3	2	250
13	**K^+**	mg/L	17	18	19	22	22	17	22	20	100
14	**HCO_3^-**	mg/L	181	166	171	146	161	146	181	165	610
15	**Cl^-**	mg/L	68	44	73	69	59	44	73	63	1000
16	**NO_3^-**	mg/L	48	50	51	51	48	48	51	50	50
17	**SO_4^{2-}**	mg/L	114	94	92	98	112	92	114	102	960

Table 5. Efficiency of station removal (%)

Par.	Aug.	Sep.	Oct.	Nov.	Dec.	Min.	Max.	Avg.
TSS	83.0	84.5	81.8	89.6	87.0	81.8	89.6	85.2
TDS	8.0	16.6	2.5	15.7	16.6	2.5	16.6	11.9
EC	8.0	16.7	4.8	13.2	22.4	4.8	22.4	13.0
BOD_5	82.3	73.4	84.9	87.3	86.1	73.4	87.3	82.8
COD	75.4	57.1	78.9	68.9	87.5	57.1	87.5	73.6
Cl^-	18.1	41.7	5.4	2.9	22.0	2.9	41.7	18.0
HCO_3^-	32.7	24.4	34.0	25.0	15.4	15.4	34.0	26.3
Na^+	3.6	14.3	1.4	11.6	3.2	1.4	14.3	6.8
Ca^{2+}	5.4	20.0	25.0	34.5	29.1	5.4	34.5	22.8
TH	11.8	3.1	1.6	4.4	3.0	1.6	11.8	4.8
Tur.	11.9	61.3	77.3	84.9	90.6	11.9	90.6	65.2
SAR	0	14.28	0	11.11	14.28	0	14.28	7.93

Table 6. Iraqi standards for disposal of treated water and agricultural irrigation (Iraq facts, 2012)

No.	Par.	Unit	Iraq facts, 2012
1	**pH**	Unit	6.4-8
2	**COD**	mg/L	100
3	**BOD**	mg/L	40
4	**TSS**	mg/L	40
5	**TDS**	mg/L	2500
6	**EC**	µS/cm	3000
7	**Ca^{2+}**	mg/L	450
8	**Mg^{2+}**	mg/L	80
9	**Na^+**	mg/L	250
10	**K^+**	mg/L	100
11	**HCO_3^-**	mg/L	610
12	**SO_4^{2-}**	mg/L	960
13	**Cl^-**	mg/L	1000
14	**NO_3^-**	mg/L	50
15	**SAR**	Unit	6 - 9

The concentration of calcium ions (Ca^{2+}) ranged between 32.13 & 59.44 milligrams per liter (mg/ L), which is less than 450mg/ L, thus falling within the Iraqi disposal regulations. The removal efficiency varied between 5.4 & 34.5%, with an average of 22.8%. The concentration of potassium ions (K^{+}) ranged between 9.53- 14.68mg/ L, which is less than 100mg/ L, adhering to the Iraqi disposal regulations. Moreover, the concentration of magnesium ions (Mg^{2+}) ranged between 38.05 & 43.9mg/ L, with an average of 42.78mg/ L, which is less than 80mg/ L, complying with the Iraqi disposal regulations. Furthermore, the concentration of sulfate ions (SO_4^{2-}) ranged between 94.5- 106.7mg/ L, with an average of 102.13mg/ L, while the concentration of nitrate ions (NO_3^{-}) ranged between 1.18- 2.78mg/ L, with an average of 49.66mg/ L. It is worth noting that, the concentrations of magnesium, potassium, nitrate, and sulfate ions were higher after the treatment process compared to raw sewage, likely due to their adsorption in the sludge thickening tank and subsequent return to the aeration tank. Moreover, concentrations often increase due to evaporation from sewage treatment and storage ponds **(Arienzo *et al*., 2009)**, and these results align with the findings of a study assessing the Thaghrah station **(Abbas *et al*., 2022)**.

3. Water quality index (*WQI*)

The water quality index (*WQI*) was calculated, and its values ranged from 95.89 to 115.09 for untreated sewage water (raw), with an average of 105.18, indicating that the water is considered unfit for use, as shown in Table (7). After treatment, the *WQI* values ranged from 32.94 to 23.59, with an average of 27.27, as shown in Table (7). The station is considered effective in improving water quality according to the *WQI*.

Table 7. Water quality index (*WQI*)

Date	Before treatment		After treatment		WQI developed by Brown *et al*. (1972)	
	WQI	***Type***	***WQI***	***Type***	***WQI***	***Water quality status***
Aug.	*103.96*	*Unfit for consumption*	*29.89*	*Good*	*0-25*	*Excellent*
Sep.	*102.32*		*32.94*	*Good*	*26-50*	*Good*
Oct.	*95.89*		*26.10*	*Good*	*51-75*	*Poor*
Nov.	*115.09*		*23.81*	*Excellent*	*76-100*	*Very Poor*
Dec.	*108.65*		*23.59*	*Excellent*	*>100*	*Unfit for consumption*
Min.	*95.89*		*23.59*	*Excellent*		
Max.	*115.09*		*32.94*	*Good*		
Avg.	*105.18*		*27.27*	*Good*		

4. The Kellys ratio (*KR*)

The Kellys ratio (*KR*) was calculated, and its values ranged from 0.31 to 0.49 for untreated sewage water (raw), with an average of 0.49. After treatment, the *KR* values ranged from 0.24 to 0.52, with an average of 0.34, which is less than 1, indicating suitability for irrigation, as shown in Table (8).

Table 8. The Kellys ratio (*KR*)

Date	**Before treatment**		**After treatment**		**Range**	
	KR	***Type***	***KR***	***Type***	***KR***	***Type***
Aug.	*0.49*	*OK*	*0.52*	*OK*	*1>*	*OK*
Sep.	*0.31*	*OK*	*0.25*	*OK*	*1<*	*No*
Oct.	*0.31*	*OK*	*0.24*	*OK*		
Nov.	*0.43*	*OK*	*0.29*	*OK*		
Dec.	*0.39*	*OK*	*0.28*	*OK*		
Min.	*0.31*	*OK*	*0.24*	*OK*		
Max.	*0.49*	*OK*	*0.52*	*OK*		
Avg.	*0.39*	*OK*	*0.34*	*OK*		

5. Sodium adsorption ratio (*SAR*)

SAR values in untreated sewage water (raw) ranged between 0.05 and 0.09, with an average of 0.07, as shown in Table (9). These values classify the water as *S1*, indicating that it is suitable for irrigation for most crops and most soils, except for crops highly sensitive to sodium. After treatment, *SAR* values ranged between 0.05 and 0.08, with an average of 0.07, as indicated in Table (9). *SAR* values fall within the Iraqi disposal standards, which are less than 9 milli-equivalents per liter, as shown in Table (6). The water is classified as S1, indicating suitability for irrigation for most crops and most soils, except for crops highly sensitive to sodium, as shown in Table (1). The efficiency of the station in reducing *SAR* values ranged between 0 and 14.28%, with an average of 7.93%, as shown in Table (5).

Table 9. Classification of water based on sodium adsorption ratio (SAR).

Date	Before treatment		After treatment	
	SAR	***Class***	***SAR***	***Class***
Aug.	*0.05*	*S1*	*0.05*	*S1*
Sep.	*0.07*	*S1*	*0.06*	*S1*
Oct.	*0.07*	*S1*	*0.07*	*S1*
Nov.	*0.09*	*S1*	*0.08*	*S1*
Dec.	*0.07*	*S1*	*0.06*	*S1*
Min.	*0.05*	*S1*	*0.05*	*S1*
Max.	*0.09*	*S1*	*0.08*	*S1*
Avg.	*0.07*	*S1*	*0.07*	*S1*

CONCLUSION

The following important conclusions can be drawn from the current evaluation of Yarmouk sewage treatment plant:

1. The treated water (effluent) from Yarmouk station complies with the Iraqi standards for both discharge and irrigation water.
2. The station's performance efficiency rates, based on the concentration of BOD and TSS in the water, were between 85.2- 82.8%, respectively. The removal ratio of other variables corresponds to their solubility in water.
3. It is worth noting that the concentrations of ions such as Mg^{2+}, K^{+}, NO_3^{-}, and SO_4^{2-} were higher after the treatment process compared to untreated sewage water (raw). This is due to their adsorption in the sludge thickening basin and then returned to the aeration basin. Additionally, concentrations often increase due to evaporation during sewage treatment and storage ponds.
4. Treated water can be used for agricultural purposes according to irrigation standards relied upon in assessing water quality (*SAR, KR, WQI* and Iraq facts, 2012).

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REFERENCES

Abawi, S. A. and Hassan, M. S. (1990). *Environmental Engineering - Water Analysis. Ministry of Higher Education and Scientific Research*, University of Mosul, Iraq.

Abbas, A. A.; Yousif, Y. T. and Almutter, H. H. (2022). Evaluation of Al-Thagher Wastewater Treatment Plant. *Periodica Polytechnica Civil Engineering*, *66*(1). https://doi.org/10.3311/PPci.18513

APHA. (2005). Standard Methods for the Examination of Water and Wastewater. *Standard Methods*. https://doi.org/ISBN 9780875532356

APHA, A. and APHA-AWWA. (2005). *Standard Methods for the Examination of Water and Wastewater*, 21st edi. American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC, USA. plant performance. *Bioresource Technology*.

Arienzo, M.; Christen, E. W.; Quayle, W. and Kumar, A. (2009). A review of the fate of potassium in the soil-plant system after land application of wastewaters. In *Journal of Hazardous Materials* (Vol. 164, Issues 2–3). https://doi.org/10.1016/j.jhazmat.2008.08.095

Culp R. L. and Culp G.L. (1971). *Advanced W.W Treat*. Van Nostrand Reinhold Co. New York.

Ebenezer, A.; Kazapoe, R. W.; Dekongmen, B. W.; Ebo, E., Amuah, Y. and Dankwa, P. (2022). *A comparative assessment of the novel water pollution index and the water quality index using empirical data: Improving water quality evaluation*. 2nd International Conference on Environment, Technology, and Management. https://www.researchgate.net/publication/366646200

Friedler, E. and Pisanty, E. (2006). Effects of design flow and treatment level on construction and operation costs of municipal wastewater treatment plants and their implications on policy making. *Water Research*, *40*(20). https://doi.org/10.1016/j.watres.2006.08.015

Hasan, M. M.; Ahmed, M. S.; Adnan, R. and Shafiquzzaman, M. (2020). Water quality indices to assess the spatiotemporal variations of Dhaleshwari river in central Bangladesh. *Environmental and Sustainability Indicators*, *8*. https://doi.org/10.1016/j.indic.2020.100068

Iraqi Facts (2012). Ministry of Justice. Wastewater Treatment Standards Used for Irrigation, (Press release)4260. https://www.moj.gov.iq/view.294/.

Jamrah, A. I. (1999). Assessment of characteristics and biological treatment technologies of Jordanian wastewater. *Bioprocess Engineering*, *21*(4). https://doi.org/10.1007/s004490050684

Kambole, M. S. (2003). Managing the water quality of the Kafue River. *Physics and Chemistry of the Earth*, *28*(20–27). https://doi.org/10.1016/j.pce.2003.08.031

Kelley, W. P. (1941). Permissible Composition and Concentration of Irrigation Water. *Transactions of the American Society of Civil Engineers*, *106*(1). https://doi.org/10.1061/taceat.0005384

Kucuksezgin, F. (1996). Multivariate analysis of water quality parameters in Izmir Bay, Eastern Aegean. *Toxicological and Environmental Chemistry*, *55*(1–4). https://doi.org/10.1080/02772249609358330

Kumar Mandal, H. (2014). Influence of Wastewater PH on Turbidity. In *International Journal of Environmental Research and Development* (Vol. 4, Issue 2). http://www.ripublication.com/ijerd.htm

Kumar Pitta, S.; Ratnakanth Babu, J.; Sundara Kumar, * K; Sundara Kumar, P. and Babu, M. J. R. (2010). PERFORMANCE EVALUATION OF WASTE WATER TREATMENT PLANT. In *Article in International Journal of Engineering Science and Technology* (Vol. 2, Issue 12). https://www.researchgate.net/publication/50384462

Lesch, S. M. and Suarez, D. L. (2009). A short note on calculating the adjusted sar index. *Transactions of the ASABE*, *52*(2).

Metcalf and Eddy Inc; Tchobanoglous, G.; Stensel, H., Tsuchihashi, R. and Burton, F. (2014). *Wastewater Engineering: Treatment, Reuse and Recovery*. *McGraw Hill, New York, NY, USA.*

Morgan-Sagastume, F. and Allen, D. G. (2003). Effects of temperature transient conditions on aerobic biological treatment of wastewater. *Water Research*, *37*(15). https://doi.org/10.1016/S0043-1354(03)00270-7

RICHARDS, L. A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. *Soil Science*, *78*(2). https://doi.org/10.1097/00010694-195408000-00012.

Salam, D.; Mohammed, Q. K.; Hassan, M. H.; Radi, A. and Ali, F. A. (2008). Evaluation of the Efficiency of a Wastewater Treatment Plant in Najaf Al-Ashraf. *Al-Kufa Journal of Chemistry*, Issue (1).

Sastry, C. A.; H. M. A. and A. P. (1995). *Waste Treatment Plants*, Narosa Publishing House. *New Delhi*. P. 435.

Tee, P. F.; Abdullah, M. O.; Tan, I. A. W.; Rashid, N. K. A.; Amin, M. A. M.; Nolasco-Hipolito, C. and Bujang, K. (2016). Review on hybrid energy systems for wastewater treatment and bio-energy production. In *Renewable and Sustainable Energy Reviews* (Vol. 54). https://doi.org/10.1016/j.rser.2015.10.011

Turgeon.a.j. (2000). *Irrigation Water Quality, College of agriculture sciences the pennsylvania State University, USA*. P. 1-8