Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(1): 257 – 270 (2025)
www.ejabf.journals.ekb.eg

Assessment of Wastewater Treatment Plants (WWTPs) Performance in El-Sharkia, Egypt

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ARTICLE INFO

Article History:
Received: Oct. 7, 2024
Accepted: Dec. 28, 2024
Online: Jan. 10, 2025

Keywords:
Wastewater treatment plants,
Assessment,
Wastewater quality index,
El-Sharkia

ABSTRACT

Reclaimed wastewater has become an important component of Egypt's water resources as a result of acute water scarcity and growing demand for various applications. The current study aimed to assess the performance efficiency of wastewater treatment plants in Egypt's El-Sharkia Governorate. The monthly reports of twenty Sharkia wastewater treatment plants (January 2023 to December 2023) included total suspended solids (TSS), ammonia (NH_3), nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{3-}), total nitrogen (TN), chemical oxygen demand (COD) and biological oxygen demand (BOD) values. The first goal of this study was to determine the per capita pollution generation per day (PCPL) from primary wastewater. The 90th percentile PCPL values for TSS, COD, BOD, TN, and PO_4 were 47.56, 120.30, 76.60, 10.97, and 0.693g/capita/day, respectively. The other goal was to determine the wastewater quality index "WWQI" to evaluate the governorate's WWTP efficiency. WWQI calculations showed that only 4 plants provide good performance (20%), 11 plants provide medium performance (55%), 4 WWTPs provide marginal performance (20%), and one WWTP is in poor condition (5%), indicating that overall performance in the governorate is rated marginal. It was demonstrated that a straightforward multiple linear regression model could accurately predict WWQI for WWTPs. The presented techniques and procedures in this paper provide an assessment framework for the wastewater treatment monitoring programs.

INTRODUCTION

Due to severe water scarcity and rising demand for a variety of uses, recovered wastewater has grown to constitute a significant part of Egypt's water resources. Wastewater treatment "WWT" is an important procedure that is needed to safeguard the environment, with a focus on successful elimination of pollutants and recovery of resources **(Pariente *et al.*, 2020)**. The World Health Organisation "WHO" claimed that

55.5% of global home wastewater was safely treated and transformed into drinkable water in 2020 **(Okadera *et al.*, 2020)**.

Wastewater treatment plants are critical structures designed to eliminate toxins, thus protecting the environment and public health. Currently, approximately 380 billion m^3 of wastewater are created annually, with an estimated 24% increase by 2030 and 51% by 2050 **(Qadir *et al.*, 2020)**.

An industrial facility known as a wastewater treatment plant (WWTP) employs a combination of physical, mechanical, chemical, and biological processes to remove contaminants from wastewater before being released back into the environment or reused. The level of treatment required for the wastewater depends on several factors including the specific effluent criteria set by regulatory authorities. These criteria dictate the acceptable quality of the treated water to ensure it meets environmental and health standards. If the treated wastewater is intended for reuse, additional treatment may be necessary to achieve the required quality for its intended purpose, whether for agricultural irrigation, industrial use, or even potable water supply **(Naidoo & Olaniran, 2014)**.

The wastewater quality index "WWQI" is a dependable and practical scientific technique for combining all the characteristic values of a complicated set of wastewater quality data into only one value for monitoring variations in wastewater quality. A number of studies provide the overall water quality using both wastewater and water quality indicators **(Praus, 2019; Sudarshan *et al.*, 2019; Jamshidzadeh & Barzi, 2020)**.

The primary objective of optimizing wastewater treatment plant (WWTP) operations is to enhance the efficiency with which all resources used within the system are utilized. This includes the careful use of personnel, energy, and reagents to prevent environmental degradation and to avoid wasting non-renewable resources **(Nadella & Sen, 2022; Rajabi *et al.*, 2022)**. However, the overarching goal of WWTPs is to produce effluent that minimizes negative impacts on both the environment and public health. To ensure this, the quality of the effluent is continuously assessed through sampling, monitoring, and evaluation. These processes generate large volumes of data on various wastewater quality parameters, which can often be unsuitable for decision-making purposes due to their complexity or inconsistency **(Yapıcıoğlu & Yeşilnacar, 2022)**.

The primary aim of this study was to calculate the daily per-capita production of wastewater pollutants, focusing on parameters such as total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), and nitrate levels, using data from WWTPs in El-Sharkia. The second goal was to assess the performance of the governorate’s WWTPs by calculating the wastewater quality index (WWQI) for the plants under study. A scientific formula for calculating the WWQI was developed based on the examined parameters, providing a comprehensive tool for evaluating the overall treatment effectiveness and for ensuring better management practices for wastewater treatment facilities.

MATERIALS AND METHODS

1. Materials

All reagents used were of analytical grade and provided by international companies such as Sigma-Aldrich, Merck, and Fisher Scientific.

2. Study area

El-Sharkia Governorate is situated 10 meters above mean sea level at longitudinal latitudes 31.63°E and 30.7°N (Fig. 1). The governorate of El-Sharkia spans 4,911km^2 with 7.86 million people living there as of 2023. Only 92.6% of the population is supplied with water through water treatment facilities with 365 M.m^3/year of capacity; wastewater treatment facilities have a capacity of no more than 146 M.m^3/year. Egypt uses 220 litres per person per day on average, while El-Sharkia Governorate uses 150 litres per person per day on average **(IWA, 2014; CAPMATH, 2023)**. Samples were taken from the entrance and outlet of twenty WWTPs in the El-Sharkia Governorate. Fig. (1) shows the locations of each WWTP.

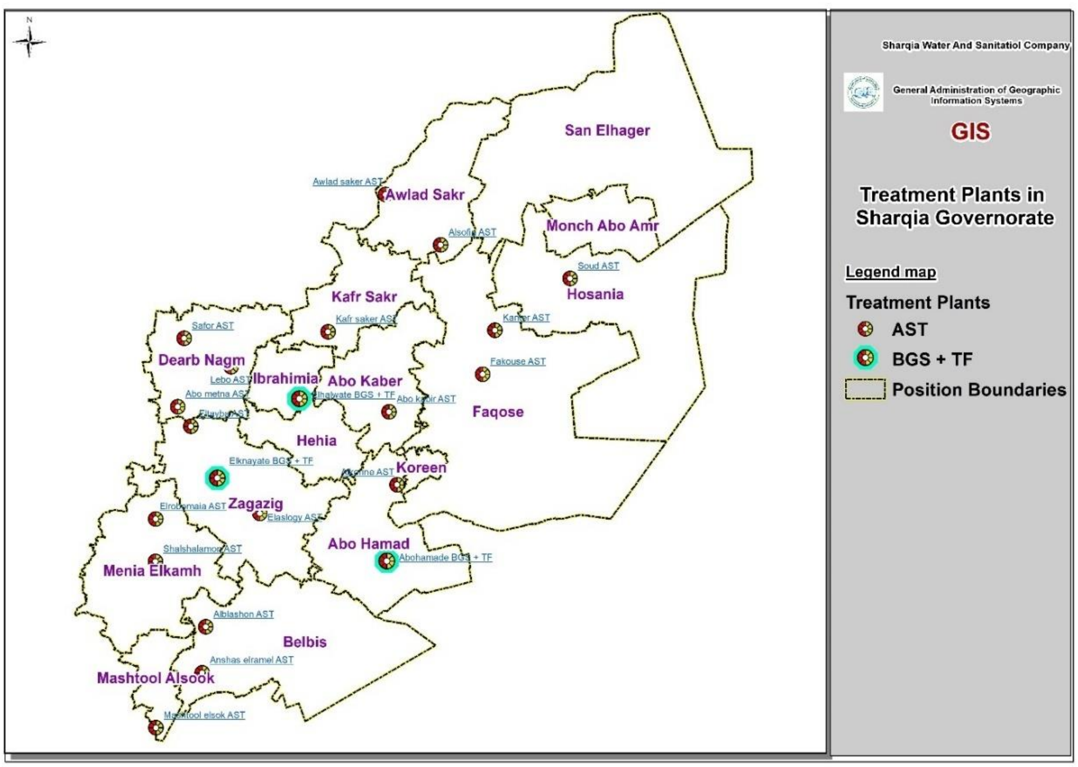

Fig. 1. Location map of WWTPs in the El-Sharkia Governorate and their treatment mechanism. (BGM + TF: Biological growth method + tricking filter; AST: Activated sludge technology)

The data for this study were gathered from monthly reports (January 2023 to December 2023) from twenty WWTPs in El-Sharkia Governorate. The following variables were reported: ammonia, nitrate, nitrite, total Kjeldahl nitrogen, total suspended solids, phosphate, chemical oxygen demand, and biochemical oxygen demand values. Samples were collected in polyethylene bottles in a cooler at 4°C to assess WWTPs performance, and averages of three readings were calculated for each parameter. All analytical methods applied in the sampling and measurement program were in accordance with the standard methods for examination of water and wastewater **(Rice *et al.*, 2012)**. Table (1) illustrates all of the analytical and reference procedures.

Table 1. Analytical and reference methods of the chemical parameters

Test	Unit	Reference method
BOD_5	mg/L	Oxi TOP Respirometric method (5210D)
COD	mg/L	Closed reflux colorimetric method (5220D) (Spectrophotometer (DR 3900 Hach)
TSS	mg/L	Solids (2540D)
Anions	mg/L	Ion chromatography (IC) Dionex ICS-1100 (anions) (Thermofisher).
TKN	mg/L:	Macro-Kjeldahl method (4500 NorgB)

Al Zagazig had a design capacity of 90,000m^3/ d, but the remaining 19 WWTPs had design capacities ranging from 10,000 to 20,000m^3/ d. Out of the 20 WWTPs, three (Abo Hamad, Qenayat, and Halawat) use biological growth systems with Trickling filters (TF) attached, where wastewater is treated to rock (gravel) media. Microorganisms grown on TF media oxidize and synthesize organic compounds in wastewater. The synthesis of biomass removes insignificant amounts of nitrogen and phosphorus. Typically, trickling filters produce effluent with BOD and TSS concentrations between 15 and 30mg/ L, which is comparable to secondary treatment **(WEF, 1998; Tchobanoglous, 2013; Qasim & Zhu, 2018)**. The remaining 17 WWTPs use the activated sludge technology, which comprises of an aeration zone for substrate usage and an additional clarifier for solids-liquid separation. It is a two-step sequential process. In well-operated systems that treat residential wastewater for at least 4 days at a solids retention time (SRT), effluent soluble BOD is usually less than 3mg/ L, while effluent total suspended solids (TSS) concentrations vary from 5 to 15mg/ L. The analysis of variance (ANOVA) and recording data was calculated using Microsoft Excel (Copyright © Microsoft 2013).

3. Wastewater quality index (WWQI)

The Canadian model of wastewater quality index (CCME-WWQI) was utilized as the foundation for assessing water quality in connection to pollutant load characterization and categorization of water under national water quality requirements for each water type in this study. Each of the three parameters that make up the index must be computed once the body of water, the time-period, and the variables and objectives have been determined. F_1 and F_2 are reasonably simple to calculate; F3 takes some additional procedures **(Bilgin, 2018)**. The WQI was calculated according to the Canadian water quality index. The following method was used to calcualte WWQI **(Bilgin, 2018)**:

(a) The measure for scope is F_1: It demonstrates the extent of non-compliance with water quality standards throughout the relevant time period.

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} \times 100 \qquad (1)$$

(b) The measure for frequency is F_2: It displays the percentage of individual tests (failed tests) that fall short of their objectives.

$$F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \qquad (2)$$

(c) The measure for amplitude is F_3: It represents the percentage of failed test values that fall short of the desired results. Three steps are involved in this:

Step 1 - Calculation of excursion: The excursion is the number of times a person's concentration surpasses (or falls below, in the case of a minimum target) the goal. When the test value should not exceed the goal:

$$\text{Excursion} = \frac{\text{Failed test values}}{\text{Guidlines}} - 1 \qquad (3)$$

When the test value must not be less than the objective:

$$\text{Excursion} = \frac{\text{Guidlines}}{\text{Failed test values}} - 1 \qquad (4)$$

Step 2 - Calculation of normalized sum of excursions (nse): The overall amount by which individual tests are out of compliance is known as the normalized sum of excursions. This is calculated by multiplying the total number of tests by the sum of individual test deviations from their aims (including those meeting and not meeting objectives) **(Bilgin, 2018)**.

$$\text{nse} = \frac{\sum \text{excursions total number of tests}}{\text{total number of tests}} - 1 \qquad (5)$$

Step 3 - Calculation of F3: It was calculated using an asymptotic function that scales the normalized sum of objective excursions to provide a range of 0 to 100.

$$F_3 = \frac{nse}{0.01\ \text{nse} + 0.01} \qquad (6)$$

The WWQI was then calculated as:

$$\text{WWQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \qquad (7)$$

After establishing the CCME WQI value, the WQI values were converted into ranks using the categorization method illustrated in Table (2) to convey water quality.

Table 2. WWQI ranks

Meaning	Percent	Grade
Safe, not damaged, and like natural values.	95 -100	Excellent
It is not a minor threat, and it is rarely observed at acceptable levels.	80 -94	Good
It is threatened in some circumstances, and not always under the appropriate settings.	65 -79	Fair
It is frequently threatened and degraded, and it is not always in the ideal state.	45 -64	Marginal
Water quality deviates from the desired level.	0-44	poor

RESULTS

1. Raw wastewater quality and per capita pollution load estimation

Table (3) presents the mean yearly raw wastewater characteristics for each WWTP and governorate. The data reveal that the WWTP inlet properties exhibit only minimal variation from one another. Specifically, the monthly average values for total suspended solids (TSS) ranged from 150.00 to 497.30mg/ L, chemical oxygen demand (COD) ranged from 307.00 to 945.00 mg/L, biochemical oxygen demand (BOD) ranged from 184.00 to 623.50 mg/L, ammonia (NH3) ranged from 16.80 to 75.00mg/ L, and total Kjeldahl nitrogen (TKN) ranged from 28.80 to 87.00mg/ L. These findings are consistent with the results reported by **Aboulfotoh and Heikal (2022)**, who evaluated 21 WWTPs during the period of 2017-2018, as well as the studies by **Mahgoub *et al*. (2015)** and **Abd-El-Kader *et al.* (2020)**. The similarity in these results suggests a consistent pattern of wastewater characteristics across different regions, supporting the reliability and relevance of the current data for evaluating the performance of WWTPs.

The 90th percentile concentrations are displayed in Table (3), which may be useful in the design of future extensions and new WWTPs. The pollution load per capita for the studied parameters could be calculated using the equation (8):

$$PCPL_i = \frac{C_i * q}{1000} \qquad (8)$$

Where, $PCPL_i$ = pollution load/capita for (i) parameter (g/capita/day);

q = sewage flow rate/capita = 0.85 * water consumption/capita = 127.50 (L/capita/day) and

C_i = Concentration for (i) parameter (mg L^{-1}).

Using TSS, NH3, TKN, COD, and BOD, the 90th percentile concentrations directed to PCPLi were found to be 47.55, 8.11, 10.97, 120.29, and 76.60g/capita/day, respectively. These findings align with the expected loads for several countries, including Denmark, Germany, and Italy, as reported by **Mesdaghinia *et al.* (2015)**. According to **Metcalf and Eddy (2013)**, Egypt's PCPL for TSS and BOD ranged from 41.00 to 68.00 and 27.00 to 41.00g/capita/day, respectively. The current study's results indicate values that are higher for BOD and fall within the maximum range for TSS. This conclusion is further corroborated by **Heikal and Aboulfotoh (2022)**, who observed similar trends in wastewater characteristics.

Table 3. Average annual raw wastewater parameters throughout the period of the study

WWTP	TSS	NH_3	NO_2	NO_3	PO_4	TKN	COD	BOD
Abo hamad	294.90	43.20	0.00	0.10	2.60	56.70	658.50	427.40
Abo kebeer	236.00	43.00	0.00	0.00	2.10	52.00	576.00	384.00
Abo metana	360.00	75.00	0.00	0.00	4.10	86.00	450.00	300.00
Balashon	271.15	47.67	0.03	0.05	6.11	61.19	615.04	406.42
Halawat	282.65	46.04	0.04	0.05	5.43	61.17	624.92	409.43
Robomea	282.65	46.04	0.04	0.05	5.43	61.17	624.92	409.43
Sawaleh	490.00	62.00	ND	ND	4.20	88.00	1800.00	1220.00
Sofia	319.20	46.80	0.03	0.03	2.87	66.80	572.40	374.80
Teba	294.33	63.00	0.02	0.02	2.30	81.33	677.67	443.67
Qenayat	356.30	50.70	0.00	0.00	3.40	60.70	540.70	359.30
Anshas	158.50	45.00	0.00	0.00	3.15	54.50	945.00	623.50
Awlad saqr	152.00	48.00	0.02	0.00	2.33	52.00	380.00	251.00
Souad	150.00	22.00	0.00	0.00	1.22	38.00	307.00	184.00
Shalshamon	231.75	40.75	0.00	0.00	2.53	54.00	518.25	332.25
Safour	497.30	69.30	0.00	0.00	2.10	87.00	943.30	598.30
Faqous	347.75	35.25	0.00	0.01	3.31	48.50	461.25	291.75
Qanteer	251.00	16.75	0.05	0.00	2.06	28.75	574.50	386.00
Kafr saqr	159.50	40.00	0.00	0.06	2.20	67.50	537.50	352.00
Lebo	291.67	46.08	0.00	0.00	3.14	53.83	625.83	404.83
Mashtool	210.00	24.00	0.00	0.00	3.15	31.00	622.50	420.00
Average	281.80	45.50	0.00	0.00	3.20	59.50	652.80	428.90
90^{th} percentile	373.00	63.63	0.04	0.05	5.43	86.10	943.50	600.85
$PCPL_i$	47.56	8.11	0.00	0.01	0.69	10.98	120.29	76.61

2. Quality of treated wastewater

The mean treated wastewater variables for each WWTP during the duration of the study period are shown in Table (4). The monthly average values of TSS varied from 14.00 to 234.66mg L^{-1}, COD from 24.00 to 223.33mg L^{-1}, BOD from 15.00 to 147.00mg L^{-1}, and TKN from 2.00 to 69.50mg L^{-1}.

According to these findings, the removal ratios for TSS, COD, and BOD are 85.14, 92.76, and 89.27%, respectively, but the absence of denitrification and the nitrification process caused the nitrate content to rise **(Nasr & Ismail, 2015; Yun *et al.*, 2018)**. Removal ratios are in line with the findings of **Mahgoub *et al.* (2015)**, who indicated that BOD, COD, and TSS may be removed at up to 90.00%, 89.00%, and 88.00%, respectively **(Metcalf & Eddy, 2013; Aboulfotoh & Heikal, 2022)**.

Table 4. Average annual treated wastewater parameters throughout the period of the study

WWTP	TSS	NH_3	NO_2	NO_3	PO_4	TKN	COD	BOD
Abo hamad	18.00	8.00	1.18	0.12	1.23	28.00	51.00	32.00
Abo kebeer	18.00	2.25	0.53	0.06	1.44	17.75	72.00	47.75
Abo metana	41.00	0.00	0.03	0.00	1.20	2.00	62.00	39.00
Balashon	43.00	43.50	0.06	0.00	1.20	69.50	90.50	60.00
Halawat	20.00	9.00	0.17	0.96	2.17	22.20	76.80	51.60
Robomea	20.20	3.40	0.58	1.62	1.70	10.80	42.80	25.60
Sawaleh	42.00	14.00	0.00	0.02	2.55	43.00	174.00	114.00
Sofia	28.00	2.60	0.49	1.16	1.84	11.00	40.00	24.60
Teba	66.67	57.33	0.01	0.00	0.83	68.33	107.00	70.67
Qenayat	20.00	1.00	2.40	1.40	2.30	7.70	37.00	20.30
Anshas	51.00	26.00	0.00	0.00	2.70	34.00	135.00	93.00
Awlad saqr	14.00	0.00	0.31	3.10	1.30	28.00	36.00	21.00
Souad	17.00	14.00	0.00	0.12	0.83	22.00	39.00	27.00
Shalshamon	25.00	3.00	0.00	3.00	2.00	14.00	49.00	29.00
Safour	234.67	43.33	0.00	0.00	1.50	62.00	223.33	147.00
Faqous	39.25	14.00	0.03	0.00	2.14	18.75	52.00	32.75
Qanteer	36.80	3.30	0.40	1.70	1.50	9.30	38.30	25.80
Kafr saqr	17.50	6.00	0.01	2.04	1.50	14.00	24.00	15.00
Lebo	69.17	7.17	0.82	0.13	2.29	13.68	62.83	40.50
Mashtool	16.00	8.00	0.01	0.20	1.65	12.50	32.50	18.00
Average	**41.86**	**13.27**	**0.35**	**0.77**	**1.68**	**25.42**	**72.25**	**46.71**

3. WWQI of the studied WWTPs

The WWQI was calculated based on the entire year's data, and Table (5) shows both the WWQI and the provincial average value. The governorate's overall performance is rated as marginal, with only 4 WWTPs providing good performance (9.52%), 11 providing fair performance (42.86%), 4 providing marginal performance (42.86%), and 1 in poor status (4.56%). The "BGM + TF" treatment technique demonstrated fair, fair, and good performance across the three WWTPs in Abo Hamed, Halawat, and Qenayat, with good removal percentages for COD and BOD, as shown in Table (5). On the other hand, the "AST" treatment technique yielded varying results for the 17 WWTPs, with 3 good, 9 fair, 4 marginal, and 1 poor performance.

Several factors influence the performance (reliability) of wastewater treatment plants, explaining why certain plants operate differently than others. These factors include the characteristics of flow variability, the inherent unpredictability of wastewater treatment process behavior (inherent reliability), the variability caused by failures, and the inexperience of wastewater treatment plant operators, particularly in developing countries. These elements contribute to the observed differences in the operational performance of the plants.

Table 5. WWQI for every plant throughout the research period

WWTPs	Treatment method*	Design capacity, m^3/d	COD removal, %	BOD removal, %	WWQI	Treatment grade
Abo hamad	BGM + TF	20000	92.00	93.00	72.00	Fair
Abo kebeer	AST	2000	88.00	88.00	69.00	Fair
Abo metana	AST	15000	86.00	87.00	71.00	Fair
Balashon	AST	4000	85.00	85.00	58.00	Marginal
Halawat	BGM + TF	20000	88.00	87.00	67.00	Fair
Robomea	AST	500	93.00	94.00	78.00	Fair
Sawaleh	AST	22000	90.00	91.00	52.00	Marginal
Sofia	AST	20000	93.00	93.00	77.00	Fair
Teba	AST	7500	84.00	84.00	53.00	Marginal
Qenayat	BGM + TF	20000	93.00	94.00	82.00	Good
Anshas	AST	10000	86.00	85.00	55.00	Marginal
Awlad saqr	AST	10000	91.00	92.00	80.00	Good
Souad	AST	10000	87.00	85.00	75.00	Fair
Shalshamon	AST	20000	91.00	91.00	73.00	Fair
Safour	AST	10000	76.00	75.00	44.00	Poor
Faqous	AST	20000	89.00	89.00	69.00	Fair
Qanteer	AST	10000	93.00	93.00	75.00	Fair
Kafr saqr	AST	10000	96.00	96.00	90.00	Good
Lebo	AST	15000	90.00	90.00	65.00	Fair
Mashtool	AST	10000	95.00	96.00	85.00	Good

*BGM + TF: Biological growth method + tricking filter; AST: Activated sludge technology.

4. Theoretical model for prediction of WWQI

Using the average observed treated wastewater quality characteristics mentioned in Table (3), the multiple linear regression (MLR) model was applied as a statistical tool to predict the wastewater quality index (WWQI) based on the treated wastewater quality parameters **(Vijayan *et al.*, 2016)**. As illustrated by equation 9, Tables (6-8) show the analysis of variance (ANOVA) results, the coefficients, and the statistical inferences from the MLR model, along with the regression statistics for the developed model.

Table (7) demonstrates that the R^2 value is 0.99, indicating that 99% of the variance in the dependent variable (WWQI) can be explained by the variation in the independent variables (treated wastewater quality parameters), as stated by **Ayoub and El-Morsy (2021)**. This high R^2 value indicates a strong fit for the model. Additionally, Fig. (2) clearly demonstrates the strong correlation between the predicted and observed WWQI values.

$$\mathbf{WWQI}_{\text{(Predicated)}} = 83.99781071 - 0.68714(TSS) - 0.74827(NH_3) + 0.318349(NO_2) + 0.570923(NO_3) - 0.13377\ (PO_4) - 0.77072(TKN) - 0.9088(COD) - 0.91563(BOD) \quad (9)$$

Table 6. ANOVA data

	df	SS	MS	F	Significance F
Regression	8	2445.301	305.6626	11.60615	0.000226283
Residual	11	289.699	26.33627		
Total	19	2735			

Table 7. Statistical results of "MLR" model

	Coefficients	Standard Error	t-Stat	P-value
Intercept	83.99781071	5.409924157	15.52661521	7.92E-09
TSS	0.001587325	0.054829044	0.028950444	0.977423
NH_3	-0.080596739	0.256547911	-0.314158625	0.759278
NO_2	-0.169919769	2.483453442	-0.068420759	0.946679
NO_3	1.419408139	1.605280297	0.884212023	0.395497
PO_4	-1.352121898	3.259567497	-0.414816352	0.686251
TKN	-0.104480148	0.227267667	-0.459722885	0.654668
COD	0.264176433	0.550569351	0.479824081	0.640751
BOD	-0.614216431	0.80349478	-0.764431141	0.460695

Table 8. Regression statistics of the model

Multiple R	0.94555653
R^2	0.894077151
Corrected R^2	0.817042352
Standard Error	5.131887758
Number of plants	20

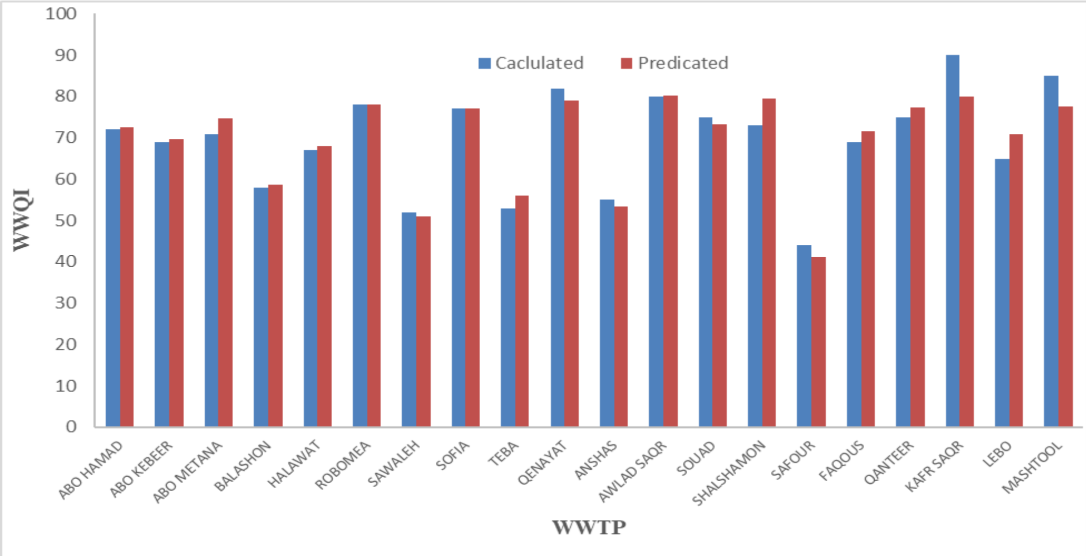

Fig. 2. WWQI calculations and predictions for WWTPs in the governorate of El-Sharkia

The estimated WWQI and the predicted WWQI using MLR model were outlined, as shown in Fig. (2), in relationship with the study period. The close values of estimated and predicted wastewater quality indices are very noticeable. Hence, the predicted WWQI using the MLR model is valid for assessing the quality of treated wastewater in El-Sharkia WWTPs.

CONCLUSION

To determine the primary source of wastewater pollution per person per day and evaluate the performance of wastewater treatment plants (WWTPs) in the governorate, data from 20 full-scale WWTPs were analyzed. The wastewater strength in the governorate was found to be between medium and elevated strength, with a tendency towards higher values. The per capita pollution loads (PCPL) for total suspended solids (TSS), ammonia (NH_3), total Kjeldahl nitrogen (TKN), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) were calculated to be 47.55, 8.11, 10.97, 120.29, and 76.60 (g/capita/day), respectively.

WWQI calculations revealed that only four plants (20%) performed well, while 11 plants (55%) provided medium performance, four WWTPs (20%) had marginal performance, and one plant (5%) exhibited poor performance. This indicates that the overall performance of the governorate's WWTPs is generally rated as marginal. To improve the effluent quality of plants with medium, marginal, and poor performance, training for technical staff and the implementation of advanced treatment technologies are essential.

The multiple linear regression (MLR) model proved to be a simple, direct, and highly accurate method for assessing the effluent quality of wastewater treatment plants in the governorate of El-Sharkia. It was shown that MLR could effectively predict the

WWQI for these WWTPs. Several factors influence the performance of wastewater treatment plants, including flow variability, the inherent unpredictability of wastewater treatment processes, variability caused by operational failures, and the lack of experience among wastewater treatment plant operators, especially in developing regions.

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