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Applying the Wastewater Quality Index for Assessing the Effluent Quality of Recently Upgraded Meet Abo El-koum Wastewater Treatment Plant

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ABSTRACT

The wastewater quality index (WWQI) can be defined as a single value, which reflects the overall wastewater quality related to its input constituent parameters. The major objective of the present study was to investigate the suitability of the effluent quality from Meet Abo El-koum wastewater treatment plant in Egypt for safe disposal based on the wastewater quality index approach. Moreover, statistical analysis was applied to develop a simple model using multiple linear regression (MLR) for accurate prediction of WWQI depending on different wastewater quality parameters. The results indicate good quality of the treated wastewater for safe disposal in general. Moreover, it is apparent that about 17% of the WWQI values reached excellent quality referring to the classification of the WWQI levels. For greater simplicity, a relationship between BOD_5 and COD was deduced using linear regression, so that the results of the BOD_5 analyses that appear after five days can be skipped. This approximation can be used to calculate WWQI on a specific day given the results of the treated wastewater analyses on that day.

Keywords: Assessment, Evaluation, Multiple linear regression, quality, wastewater, WWTP

INTRODUCTION

Water quality index (WQI) provides a single dimensionless value that indicates the overall water quality under specified conditions of time and location depending on various water quality parameters. In most cases, WQI is applied to assess the quality of water resources and potability of the treated water (Praus, 2019; Phadatare and Gawande, 2016; Tsakiris, 2016; Tyagi et al., 2013; WHO, 2018). The idea of WQI was pioneered by Horton (1965) and developed by Brown et al. (1970) to be a decision-making tool for planners, stakeholders in addition to the governmental authorities and agencies to facilitate smart management of the water quality issues (Hossen and Jishan, 2018; Vijayan et al., 2016; Tsakiris, 2016; Badr et al., 2013; Libânio and Lopes, 2009). This concept of WQI is applied to wastewater and the quality of the wastewater may be determined based on the wastewater quality index (WWQI). The wastewater quality index can be defined as a single value, which reflects the overall wastewater quality related to its input constituent parameters (Chmielowski et al., 2020; Jamshidzadeh and Barzi, 2020; Ibrahim, 2019; Praus, 2019; Vijayan et al., 2016).

Weighted Arithmetic Water Quality Index Method (WAWQIM) is an accomplished method for developing and categorizing WQI (Hossen and Jishan, 2018; Oni and Fasakin, 2016; Yogendra and Puttaiah, 2008). Oni and Fasakin (2016) applied Weighted Arithmetic WAWQIM to assess potability of the surface and groundwater in Nigeria. In addition, Yogendra and Puttaiah (2008) applied WAWQIM to assess the appropriateness of an urban water body in Shimoga

Town, Karnataka. These researchers concluded that WAWQIM is an influential approach that guarantees the suitability of water for human consumption in the case of freshwater bodies. Furthermore, Phadatare and Gawande (2016) informed that the WAWQIM method is beneficial globally for evaluating, monitoring and impact studies for different water bodies.

Ibrahim (2019) applied WAWQIM for evaluating the suitability of effluent quality of a wastewater treatment plant (WWTP) in Jordan for the irrigation purpose. The treated wastewater quality was categorized to be suitable for different types of agricultural crops based on the estimated WWQI. Moreover, Jamshidzadeh and Barzi (2020) merged twenty-three wastewater parameters to develop WWQI for assessing the effluent quality of Isfahan North WWTP. Therefore, WWQI is a useful tool for researchers and decision-makers to monitor and assess the wastewater quality. It is also helpful for the public to understand the treated wastewater quality for any purpose (Jamshidzadeh and Barzi, 2020; Praus, 2019; Ibrahim, 2019). The major objective of the present study was to investigate the suitability of the effluent quality from a newly upgraded wastewater treatment plant in Egypt for safe disposal based on the wastewater quality index approach.

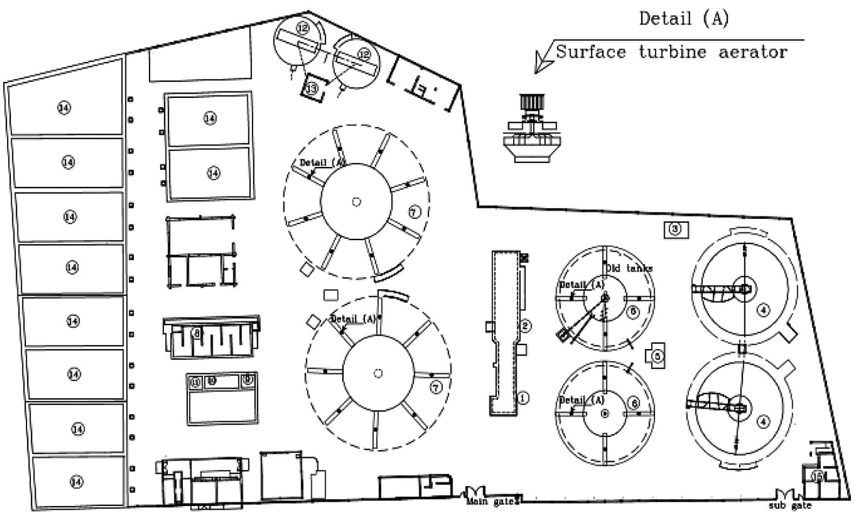
METHODOLOGY

Study area

A recently upgraded WWTP shown in Figure 1 receives 10,000 m^3/d of municipal wastewater. The WWTP was implemented in Meet Abo El-koum village, El-Menoufya Governorate (about 65 km from Cairo, Egypt). The WWTP had been previously operating with an extended aeration system with a capacity of 4,600 m^3/d, and it was newly developed to accommodate 10,000 m^3/d of wastewater. The upgrading involved regular installation of surface turbine aerators on the aeration tanks and construction of primary sedimentation tanks.

The analyses results of treated wastewater

The treated effluent wastewater characteristics were collected and statistically analyzed as denoted in Table 1. The parameters and the equipment utilized in the laboratory tests are represented in Table 2. All tests were conducted in the Lab of WWTP according to Standard Methods (2017) for the Examination of Water and Wastewater, 23rd edition. These experiments were conducted from October 2019 till September 2020 under the supervision of El-Menoufya Water and Sanitation Company (MWSC, 2020).



No	Item	No	Item	No	Item
1	Bar screens	6	First size of the compact unit for aeration and final clarification	11	Supernatant pump station
2	Grit Removal	7	Second size of the compact unit for aeration and final clarification	12	Sludge concentration tanks
3	Distribution Chamber	8	Chlorination contact tank	13	Sludge pump station
4	Primary Sedimentation Tank (New)	9	Primary Sedimentation sludge pumping station	14	Sludge drying beds
5	Areation tanks Distribution Chamber	10	excess sludge pumping station	15	Administartion and Lab. building

Figure 1. A general layout of the upgraded WWTP located in Meet Abo El-koum village

Table 1. Descriptive statistics of the treated effluent wastewater characteristics of Meet Abo El-koum WWTP

Parameter	The treated effluent (secondary treated wastewater) characteristics				
	Max.	Min.	Average	Standard deviation	Limits for treated effluent*
Temperature (T) (ºC)	22.8	20.5	21.62	1.01	25–30
pH	7.5	7.3	7.38	0.084	6.5–8.5
Total dissolved solids (TDS) (mg/L)	811	714	778.8	37.82	≤2000
Total suspended solids (TSS) (mg/L)	42.5	20	30.5	8.18	≤50
Dissolved oxygen (DO) (mg/L)	5.0	4.3	4.66	0.3	≥4
Chemical oxygen demand (COD) (mg/L)	51	39	45.4	4.83	≤80
Biochemical oxygen demand (BOD_5) (mg/L)	30	25	28.6	2.19	≤60
Oil and grease (O&G) (mg/L)	9.6	8.7	9.2	0.25	≤10

Notes: * Adapted from Metcalf and Eddy (2003)

Table 2. Parameters and equipment utilized in the laboratory tests

Parameter	Equipment and product information
COD (mg/L)	COD reactor (DINKO), and spectro-photometer(*biochrom*) Model Libra S12
BOD_5 (mg/L)	BOD incubation (Fisher Scientific), USA
pH, Temperature (ºC)	pH / ˚ C Model CONSORT P400
Total solids (TS) (mg/L)	Drying oven (BINDER®) company-Analytical balance (OHAUS®), Germany

Calculation method of water quality index

The weighted arithmetic water quality index method (WAWQIM) was applied in this study for calculating WQI by means of the following equation (Oni and Fasakin, 2016; Phadatare and Gawande, 2016):

$$WQI = \frac{\sum q_n W_n}{\sum W_n} \quad (1)$$

where: q_n= quality rating of n^{th} water quality parameter, and
W_n= unit weight of n^{th} water quality parameter

The following equation was applied for estimating the quality rating (q_n)

$$q_n = (\frac{V_n - V_{id}}{S_n - V_{id}}) \times 100 \quad (2)$$

where: V_n= estimated value of n^{th} water quality parameter,
V_{id}= ideal value for n^{th} parameter (i.e. for pH, V_{id} = 7.0, and V_{id} = zero for the other parameters), and
S_n= standard permissible value of n^{th} water quality parameter

The unit weight (W_n) was calculated using the following equation:

$$W_n = \frac{K}{S_n} \quad (3)$$

where: S_n= standard permissible value of n^{th} water quality parameter, and
K= constant of proportionality. It was calculated using the following equation:

$$K = \frac{1}{\sum \frac{1}{S_n}} \quad (4)$$

When applying this WQI concept to wastewater, the wastewater quality can be determined based on the WWQI. Rating of WWQI and corresponding grade of the treated wastewater are displayed in Table 3.

RESULTS AND DISCUSSION

WWQI during the study period

Comparing the results of the treated wastewater quality analyses shown in Table 4 with the limit of the effluent treated wastewater presented in Table 1 revealed that the treated wastewater quality conforms to the international standards of secondary treated wastewater (WHO, 2018, Metcalf and Eddy, 2003). Furthermore, WWQI was calculated using WAWQIM for each month during the study period as shown in Table 4.

The monthly WWQI values ranged between 21.4 and 40.5 with an average value of 31.63 through the study period, which indicates good

Table 3. Rating and grade of the wastewater quality for corresponding levels of WWQI (WHO, 2018; Jamshidzadeh and Barzi, 2020)

WWQI level	Rating of wastewater quality/ Grade
0–25	Excellent / A
26–50	Good / B
51–75	Regular / C
75–100	Bad / D
>100	Very bad / E

quality of the treated wastewater for safe disposal in general. Moreover, it is apparent that about 17% of the WWQI values reached excellent quality referring to the classification of the WWQI levels in Table 3 (WHO, 2018; Jamshidzadeh and Barzi, 2020).

Model development for predicting WWQI

Multiple linear regression (MLR) model was applied as a statistical tool for the prediction of WWQI depending on the recorded treated wastewater quality parameters (Vijayan et al., 2016). The output data from the analysis of variance (ANOVA) model are shown in Table 5, whereas coefficients and statistical results from the MLR model are represented in Table (6).

The predicted WWQI from MLR model can be calculated using the following derived equation:

$$WWQI = 3.553T + 22.325pH + 0.038TDS + \\ + 0.392TSS - 13.538DO - 4.017COD + \\ + 5.779BOD_5 - 18.84O\&G \quad (5)$$

WWQI was considered a dependent variable, while the parameters of wastewater quality were independent variables in MLR confirmed by R-squared value of 0.994. Therefore, MLR is a simple, direct, and very accurate model for assessing the effluent quality of the Meet Abo El-koum wastewater treatment plant.

The estimated WWQI using WAWQIM and the predicted WWQI using MLR model were outlined as shown in Figure 2, in relationship with the study period (from October 2019 till September 2020). 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 Meet Abo El-koum WWTP, given the values of treated wastewater characteristics. For greater simplicity, a relationship between BOD_5 and COD can be deduced using linear regression as shown in Figure 3, so that

Table 4. Average monthly results of the different parameters and corresponding values of WQI from October 2019 till September 2020

No	Month	Temperature – °C	pH	TDS – mg/L	TSS – mg/L	DO – mg/L	COD – mg/L	BOD5 – mg/L	(O&G) -mg/L	WWQI	Grade
1	Oct-19	22.5	7.5	785	32.5	4.4	51	28	8.7	27.1	B
2	Nov-19	20.8	7.4	799	27.5	4.8	42	30	9.6	43.2	B
3	Dec-19	22.8	7.3	811	42.5	5	48	30	9.2	31.8	B
4	Jan-20	20.5	7.4	714	30	4.3	47	30	9.1	30.2	B
5	Feb-20	21.5	7.3	785	30.5	4.8	39	25	9.2	29.4	B
6	Mar-20	20.5	7.4	784	32	4.7	49	30	8.6	32.5	B
7	Apr-20	20.8	7.3	779	42	4.9	40	28	9.6	35.2	B
8	May-20	21.5	7.4	786	28	4.3	48	28	9.3	21.6	A
9	Jun-20	21.6	7.3	798	31	4.5	49	30	9.2	21.4	A
10	Jul-20	21.6	7.5	779	21	5	41	27	9.1	34.1	B
11	Aug-20	22.8	7.4	779	30.5	4.8	45	29	9.2	40.5	B
12	Sep-20	22.5	7.4	812	20	4.7	46	30	9.2	32.5	B

Table 5. Output data from analysis of variance (ANOVA) model

Source	df	SS	MS	F	Significance F
Regression	8	11658.6025	1457.325312	58.76509066	0.01683745
Residual	3	74.39750178	24.79916726		
Total	11	11733			

Table 6. Coefficients and statistical results of multiple linear regression model

Specification	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.000	#N/A	#N/A	#N/A	#N/A	#N/A
Temperature (T) – °C	3.553	3.617	0.983	0.398	-7.956	15.063
pH	22.325	23.931	0.933	0.420	-53.835	98.485
TDS – mg/L	0.038	0.134	0.286	0.793	-0.388	0.465
TSS – mg/L	0.392	0.567	0.691	0.539	-1.413	2.198
DO – mg/L	-13.538	28.119	-0.481	0.663	-103.024	75.948
COD – mg/L	-4.017	2.603	-1.543	0.221	-12.301	4.268
BOD_5 – mg/L	5.779	2.761	2.093	0.127	-3.007	14.566
O & G- mg/L	-18.840	17.782	-1.059	0.367	-75.430	37.751

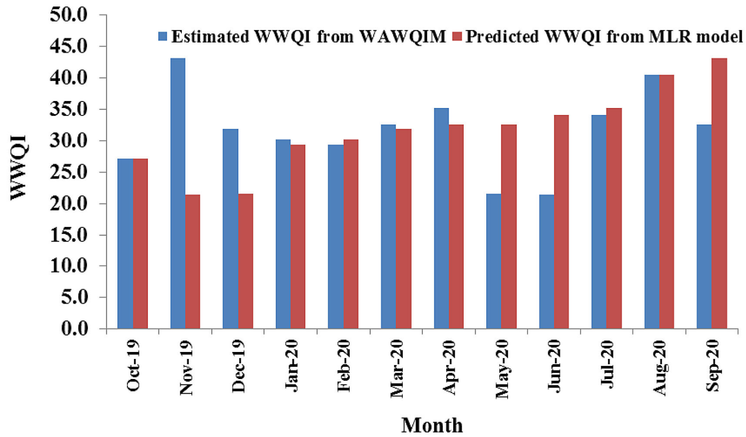


Figure 2. Variation of estimated and predicted WWQI throughout study period

the results of the BOD_5 analyses that appear after five days can be skipped. This approximation can be used to calculate WWQI on a specific day given the results of the treated wastewater analyses on that day.

With reference to Figure 3, the relationship between BOD_5 and COD can be expressed by using the following equation:

$$BOD_5 = 0.6302COD \quad (6)$$

By substitution into equation (5), the following equation can be obtained

$$\begin{aligned} WWQI = 3.553T + 22.325pH + 0.038TDS + \\ + 0.392TSS - 13.538DO - 0.375COD - \\ - 18.84O\&G \end{aligned} \quad (7)$$

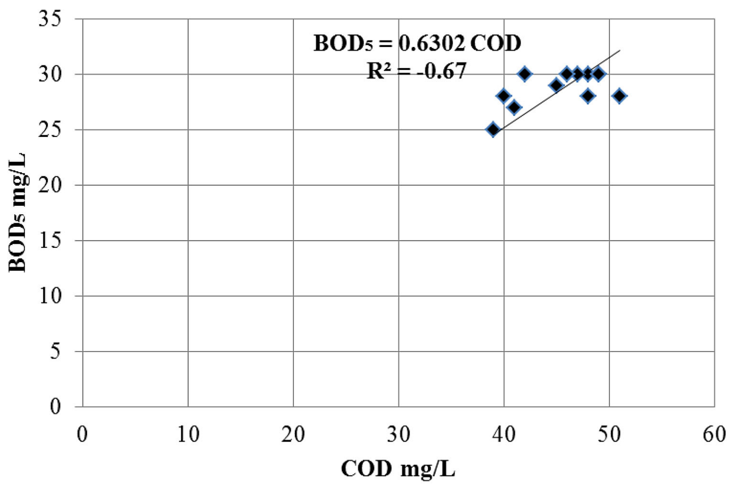


Figure 3. Correlation between BOD_5 and COD using linear regression

CONCLUSIONS

The wastewater quality index can be defined as a single value, which reflects the overall wastewater quality related to its input constituent parameters. The monthly WWQI values ranged between 21.4 and 40.5 with an average value of 31.63 through the study period, which indicates good quality of the treated wastewater for safe disposal in general. Moreover, it is apparent that about 17% of the WWQI values recorded excellent quality referring to the classification of WWQI levels. On the other hand, MLR is a simple, direct, and very accurate model for assessing the effluent quality of the Meet Abo El-koum wastewater treatment plant. For greater simplicity, a relationship between BOD_5 and COD was deduced using linear regression, so that the results of the BOD_5 analyses that appear after five days can be skipped. This approximation can be used to calculate WWQI on a specific day given the results of the treated wastewater analyses on that day.

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