

Modelling and Simulation of a Wastewater Treatment System – Case Study: The 10th of Ramadan City, Egypt

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Abstract

The 10th of Ramadan City suffers from poor management of the wastewater treatment process due to the lack of the necessary infrastructure. The WWTP receives domestic wastewater, and some contribution from the industrial buildings (Factories of shoes, clothes, furniture, consumer electronics, and household electrical appliances) ranged from 90,000 m³/day to 130,000 m³/day. From this, the need arose to study the extent to which industrial wastewater was affected by the treatment processes. Several equations were prepared by the IWA Task Group to try to understand the processes that take place during biological treatment in what is now known as activated sludge models (ASM). In the application of one of these models, the Activated Sludge Model No. 1 (ASM1) was used to simulate the 10th of Ramadan WWTP in Egypt via computer-supported programs (STOAT 5.0 software) to describe the performance of the 10th of Ramadan WWTP in its current state. The kinetic and stoichiometric parameters were selected to be calibrated, which changed because of the novel variation in temperature within the plant and because of the presence of the industrial wastewater. This study concluded a discrepancy between the results and field samples, and the results obtained from the simulation model ranging from 13% to 20% for the variables (COD, TSS, TVSS, and DO). This indicates a discrepancy in the actual performance of the 10th of Ramadan WWTP from its ideal condition. This is likely due to some contributions from industrial facilities to the upcoming disposal of the plant.

Keywords: Activated sludge, ASM, Modelling, wastewater, WWTP

INTRODUCTION

The activated sludge process is the foremost prevalent biological treatment of wastewater. It was developed around 100 years ago by Clark and Gage in Massachusetts and by Arden and Lockett in Manchester, England (Metcalf and Eddy, 2003). During this process, the suspension of bacterial biomass is chargeable for the removal of pollutants. Looking at the particular design and application, the activated sludge wastewater treatment plant can do the removal of biological nitrogen, and the removal of biological phosphorus, beside the removal of organic carbon substances (Von Sperling, 2007; Šikić et al., 2019; Di et al., 2020; Jasim, 2020).

Increased knowledge about the varied organic process mechanisms that occur within the activated sludge (AS) plant is translated into dynamic models developed to explain the decomposition processes within the activated sludge system. The mathematical modeling of the stimulant protectors has become better due to increased knowledge of the processes administered within the AS reactor has increased over the years (Mhlanga, 2016, Hu et al., 2019, and Tian et al., 2020). Mathematical modelling of AS systems has become a widely accepted tool for research, plant design and improvement, and the training of process engineers and plant operators. Mathematical models are useful in the condition that the model predictions are reliable (Sin, 2004, Drewnowski, 2019, and Panepinto et al., 2020).

The task group published ASM1 (Henze et al., 1987) which was meant to come back with minimum complexity and to supply a platform for the future development of models for nitrogen-removal activated sludge processes (Henze et al., 2000).

ASM1 set the baseline for the development of further ASM's. When the ASM1 was published, biological-phosphorus removal was already in use in an exceedingly limited number of WWTPs. From the mid-1980s to the mid-1990s, the employment of biological phosphorus removal processes increased and the understanding of the processes was increasing. Consequently, in 1995 ASM2 was published, which includes nitrogen-removal and biological phosphorus removal processes (Henze et al., 1995). In 1999 the ASM2 model was expanded to ASM2d to include denitrifying phosphorus accumulating organisms (PAOs) after it became evident that denitrifying PAOs were required to simulate and explain the results from research and practice (Henze et al., 2000). In 1998, the task group developed the ASM3. The ASM3 was developed for biological nitrogen removal like ASM1. The improved ASM3 was developed to correct defects that are identified by users of ASM1 (Gujer et al., 1999; Ladhari et al., 2019).

STOAT 5.0 is that the simulation program supported BOD and COD and has been utilized in many regions like Britain, Europe, the Middle East, and the USA to assist the industry with better understanding and application of the wastewater treatment model (Ayoub, 2018; Hodgson and Sharvelle, 2019).

This study aims to assess the validation of ASM1 after being calibrated for primary and the secondary treatment in the 10th of Ramadan City WWTP, Al-Sharkia Governorate Egypt. This study focuses on the tasks of influent characterization and model calibration with the purpose of constructing an acceptable model that reflects the performance of the station.

METHODOLOGY

The good modelling practice (GMP) unified protocol was applied within the present study for activated sludge modelling and efficient process simulation of the integrated wastewater treatment system (Rieger et al., 2012; Elawwad et al., 2017a; 2017b; Ayoub, 2018; Hodgson and Sharvelle, 2019). The GMP consists of the subsequent consecutive steps: project definition, data collection, setup of WWTP model, simulation, calibration and validation, and eventually analysis of results and evaluation (Rieger et al., 2012; Elawwad et al., 2017a; 2017b; Ayoub, 2018).

2.1 Methodology - Study area description:

The 10th of Ramadan City is the first of the new cities in Egypt and one of the cities of the 1st generation. Its planning began in the aftermath of the October 1973 war, specifically in 1975; it began to be established in 1977 to achieve several key objectives representing the state's policy of redistributing the population in Egypt by creating new attractions outside the existing towns and villages to limit the extent of the expansion of the country. The city is located on the Cairo/Ismailia Desert Road, about 55 km from the center of Cairo. The WWTP receives domestic wastewater, and some contribution from the industrial buildings (Factories of shoes, clothes, furniture, consumer electronics, and household electrical appliances) ranged from 90,000 m³/day to 130,000 m³/day.

The 10th of Ramadan WWTP is carried out in three stages of primary, biological and tertiary treatment, and in this research study is limited to biological treatment. The preliminary treatment begins with the entry of raw wastewater into the screens and the grit removal chamber. Then, wastewater flows to the primary sedimentation tanks. Biological treatment with activated sludge system is used through extended aeration tanks where a micro-aeration system is used to increase oxygen efficiency, then the final sedimentation stage begins from there to the chlorination tanks for disinfection, as shown in Figure (1).

2.2 Methodology - Model development:

Model simulation of the 10th of Ramadan City WWTP was completed as shown in Figure (2) using STOAT 5.0 software by WRc plc. Figure (2) represents a configuration of the 10th of Ramadan WWTP within the current status including, screens, grit removal chamber, primary sedimentation tanks, aeration (biological treatment) tanks, final clarifier, chlorination tank. The ASM1 model supported Monod kinetics that predicts the processes of biological reactions. The ASM1 models COD and N removal, oxygen consumption, and sludge production. Wastewater is characterized in terms of seven dissolved and particulate components that are accustomed to describe two biomass groups, seven fractions of COD (organic material) (Henze et al. 1987). After model calibration, the model of the 10th of Ramadan City WWTP can be evaluated by comparing the treated wastewater characteristics (outputs from STOAT 5.0) to the effluent from secondary treatment (Ayoub, 2018; Hodgson and Sharvelle, 2019).

2.3 Methodology - Operational parameters and wastewater characteristics:

Results of the operational parameters and wastewater characteristics of the 10th of Ramadan City WWTP were collected during the period from November 2019 to January 2020 for model validation as appeared in Table (1) for the wastewater characteristics and Table (2) for the operational parameters. These data were statistically analyzed to acquire the mean values and standard deviations for each parameter during the data collection period.

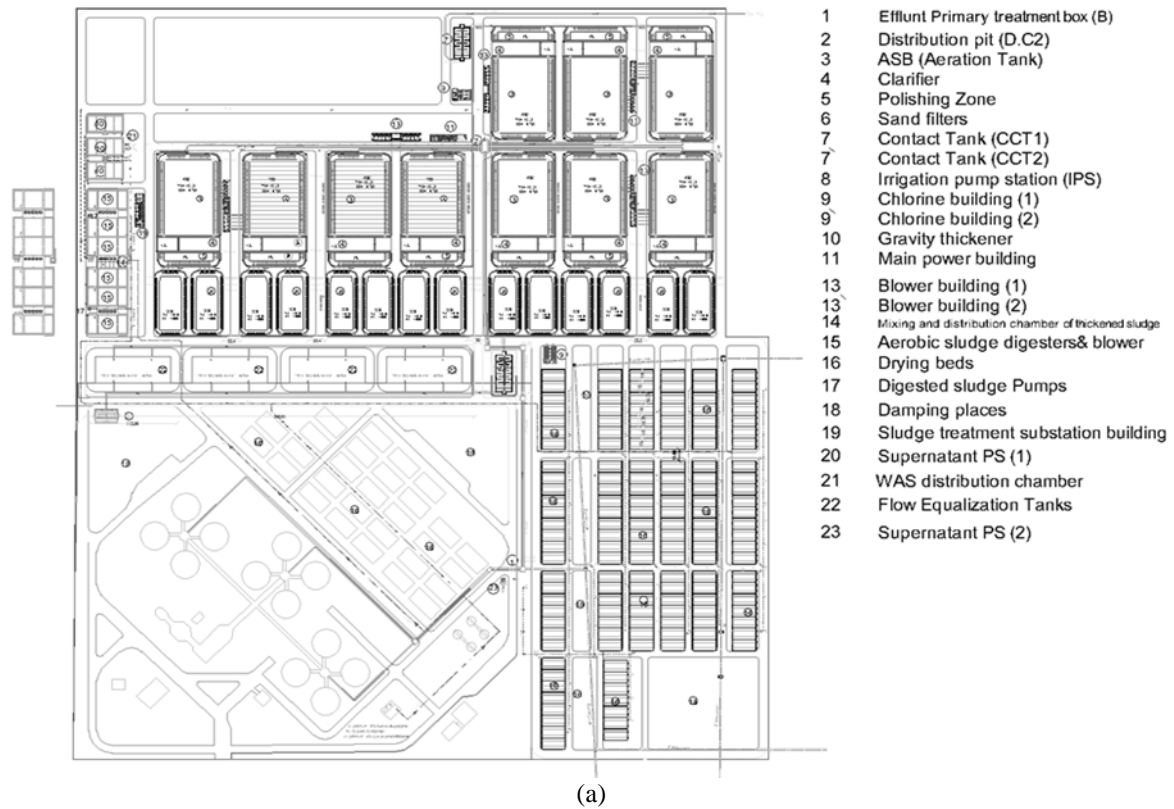


Fig. 1: The 10th of Ramadan WWTP in (a) a general layout, (b) an adapted photo from Google earth, (February, 2020)

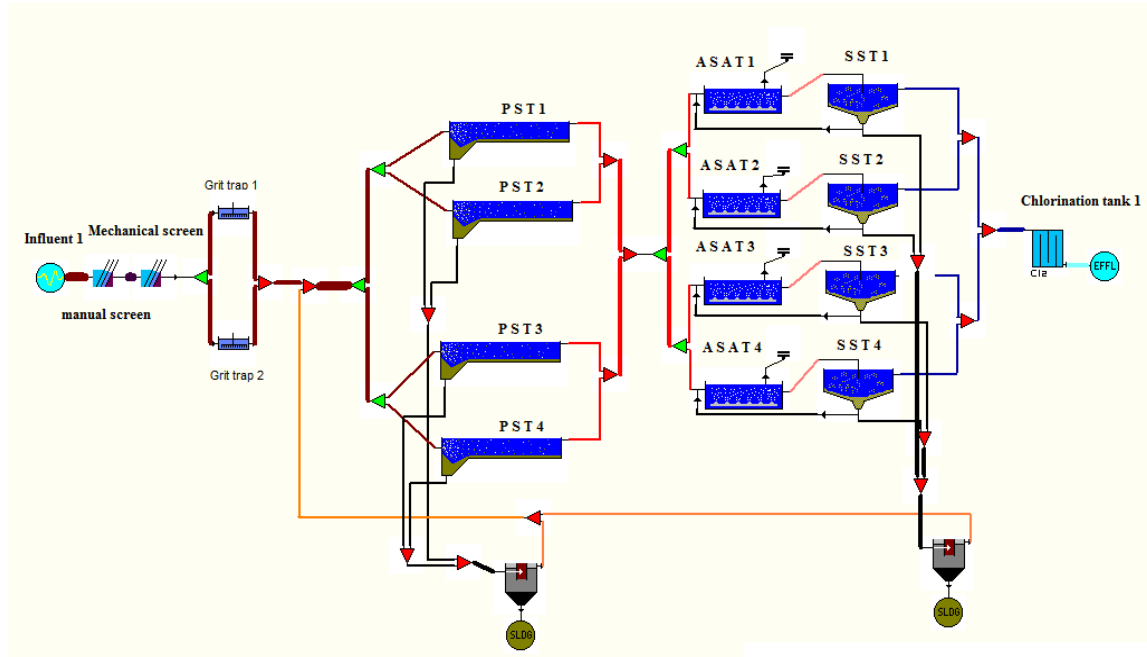


Fig. 2: Model of the 10th of Ramadan WWTP by STOAT 5.0 software

Table 1: The 10th of Ramadan WWTP average of historical daily routine measurements over 3 months

Parameter	Unit	Influent (Raw Wastewater)	Effluent from Secondary Treatment	Range*
Discharge	m ³ /d	110,000	—	—
DO	mg/L	0.24 ± 0.06	5.8 ± 0.54	Above 4
pH	—	6.42 ± 0.25	6.91 ± 0.2	6 to 9
Temperature	°C	—	—	—
TSS	mg/L	216 ± 41.91	21.1 ± 8.93	50
TVSS	mg/L	129 ± 25.28	11.45 ± 4.10	—
COD	mg/L	726.25 ± 69.9	55.5 ± 9.86	80
BOD ₅	mg/L	433.88 ± 41.20	32.10 ± 5.57	60

Notes: * Adapted from Law No. 93 of 1962.

Table 2: The operational parameters of the 10th of Ramadan WWTP.

Parameter	Average value	Design criteria (Metcalf and Eddy, 2003)
Aeration period (θ) (hr)	30	18-36
Mean cell residence time (θ_c) (day)	20	20-30
Mixed liquor suspended solids (MLSS) (mg/L)	4000	4000-8000
Food/Mass of microorganisms (F/M) (Kg BOD ₅ /Kg MLSS)	0.042	0.05-0.15
Volumetric loading rate (VL) (Kg BOD ₅ /m ³ .d)	0.168	0.16-0.40
Return activated sludge (RAS) ratio (%)	54%	75-200%

The COD fractions for settled sewage was divided according to proportions from (Pasztor et al., 2009) as shown in Table (3).

Table 3: COD fractions for raw sewage (Pasztor et al., 2009)

Parameter	Name	Ratio (Pasztor et al., 2009)	Value
Ss	Soluble biodegradable COD (mg/L)	17.5%	127 ± 12.23
Si	Soluble nonbiodegradable COD (mg/L)	7.5%	54.75 ± 5.24
Xs	Particulate biodegradable COD (mg/L)	57.9%	420.5 ± 40.5
Xi	Particulate nonbiodegradable COD (mg/L)	17.1%	124.2 ± 11.95

RESULTS AND DISCUSSION

3.1 Results and Discussion- Model Calibration

The hydrodynamic behavior is a critical part of model calibration, which has been found to determine the prediction of pollutant elimination and sample strategies in municipal wastewater treatment plants (WWTPs) (Majewsky et al., 2011). Since the

series of ASM are developed and are continuously being improved, these values serving as critical parameters in Monod equations of various biological processes are found to be in a wide range (Zeng, 2013).

The current status of the 10th of Ramadan WWTP has been simulated using IAWQ #1: "equivalent ASM1" for modelling the biological treatment and use the generic model of secondary sedimentation tank with their default values of the kinetic and stoichiometric parameters in STOAT 5.0 software. According to (Henze et al. 1987), the kinetic and stoichiometric parameters were selected to be calibrated, which are the maximum heterotrophic growth rate, the aerobic endogenous respiration of heterotrophic biomass, and aerobic yield of heterotrophic biomass. In addition, adjustment of these parameters needs trial and error methodology to get the lowest difference between the measured and simulated values of wastewater characteristics. The calibrated values of Heterotroph growth rate (μ_H), Autotroph growth rate (μ_A), Heterotroph death rate (bH), Autotroph death rate (bA), Ammonification rate (Ka), Hydrolysis rate, Yield of the heterotrophic organisms (YH), and Yield of the Autotroph organisms (YA) can be calculated by equations from tutorials of the STOAT 5.0 (WRC, 2012). All units of WTTP (Screens, grit removal tank, primary sedimentation tanks, final sedimentation tanks) were calibrated according to the f tutorials of the STOAT 5.0 (WRC, 2012).

Heterotroph growth rate and Autotroph growth rate: The maximum specific growth rate is calculated at any sewage temperature from the equation.

$$\mu = \mu_{\max} * e^{[\theta * (T - 15)]}$$

- Heterotroph death rate, and Autotroph death rate: The death rate is calculated using the equation

$$\text{Death} = \text{Death Rate at } 15 * e^{[\theta * (T - 15)]}$$

- Ammonification rate: Ammonification is the process of converting soluble organic nitrogen into free ammonia or ammonium. The rate constant is calculated using the equation.

$$\text{Ammonification Rate} = \text{Ammonification Rate at } 15 * e^{[\theta * (T - 15)]}$$

- Hydrolysis is the breaking down of particulate BOD to soluble BOD, and of particulate organic nitrogen to soluble organic nitrogen. The rate constant is calculated by the equation.

$$\text{Hydrolysis rate} = \text{Hydrolysis rate at } 15 * e^{[\theta * (T - 15)]}$$

Where:

θ : Temperature coefficient

T: Sewage temperature.

The calibrated values and the default values in STOAT 5.0 software of kinetic and stoichiometric parameters were presented in Table (4).

Table 4: Calibrated ASM1 kinetic and stoichiometric parameters

Parameter	Symbol	Units	STOAT default values "at 15 °C "	This Study values "at 22 °C "
Heterotroph growth rate	μ_H	h-1	0.1768	0.2872
Autotroph growth rate	μ_A	h-1	0.0207	0.0419
Heterotroph death rate	bH	h-1	0.0147	0.0324
Autotroph death rate	bA	h-1	0.0142	0.0313
Ammonification rate	Ka	h-1	0.0024	0.0039
Hydrolysis rate	----	h-1	0.0722	0.1558
Yield of the heterotrophic organisms	YH	gm COD/ gm. COD	0.67	Use default value"0.67"
Yield of the Autotroph organisms	YA	gm. COD/ gm. N	0.24	Use default value"0.24"

After building the model and entering all the data on the units as well as the characteristics of the raw water over a period of 3 months, the model was calibrated according to the Parameter from Table (4) in the program, which is a simulation of the performance of the plant and the results of the treated water were extracted according to Table (5).

Table 5: The wastewater characteristics of the 10th of Ramadan WWTP and the treated water form calibrated model

Parameter	Unit	Influent (Raw Wastewater)	Effluent (Treated Wastewater)
Discharge	m ³ /d	110000 ± 11000	54000 ± 4250
DO	mg/L	0.24 ± 0.06	6.89 ± 0.35
pH	—	6.42 ± 0.25	7 ± 0.0
Temperature	°C	—	23.1 ± 0.51
TSS	mg/L	216 ± 41.91	17.11 ± 1.41
TVSS	mg/L	129 ± 25.28	12.62 ± 1.10
COD	mg/L	726.25 ± 69.9	61.11 4.92

3.2 Results and Discussion- Model validation:

3.2.1 Model validation - COD analysis:

The influent COD entered into the STOAT 5.0 software as the influent COD is measured at the plant. As shown in Figures (3, 4). The influent COD from the analysis of samples for a period of three months is 726.25 ± 69.9 mg/L, the effluent COD for treated wastewater is 55.5 ± 9.86 mg/L, and the effluent COD from simulated STOAT 5.0 model is 61.11 ± 4.92 mg/L with (Root Mean Square Deviation) RMSD is (8), and the normalized root mean square deviation (NRMSD) is 13.58%, as shown Figure (3, 4) & Table (6).

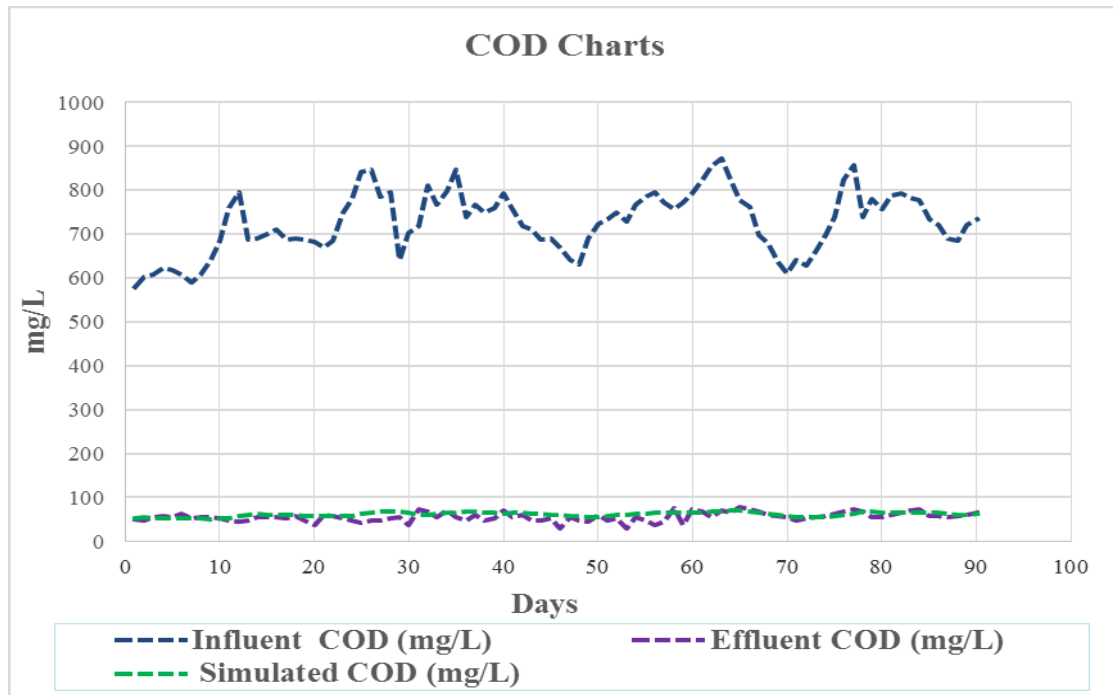


Fig. 3: Influent, effluent, and simulated effluent COD

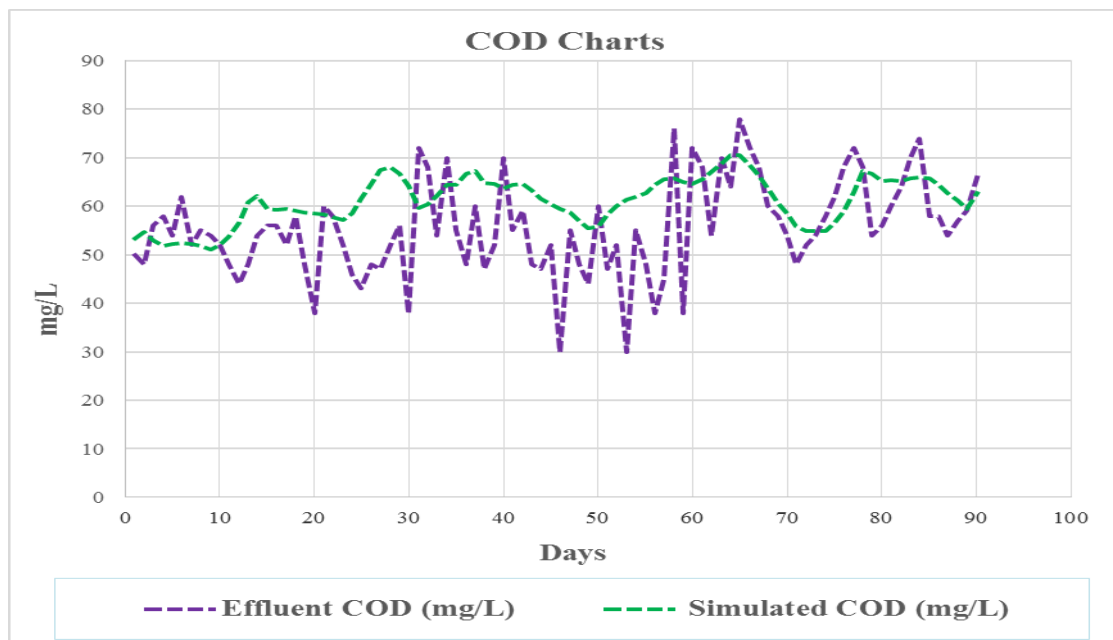


Fig. 4: Effluent and simulated effluent COD

3.2.2 Model validation - TSS and TVSS analysis

The model also describes the total suspended solids concentrations in the influent, effluent and in return activated sludge (RAS). The TSS removal efficiency in the final sedimentation tanks plays a major role in the TSS values in the effluent and the RAS and consequently affects the COD in the effluent. Final sedimentation tank removal efficiency was calibrated at 95%.

The influent TSS from the analysis of samples for a period of three months is 216 ± 41.91 mg/L, the effluent TSS for treated wastewater is 21.1 ± 8.93 mg/L, and the effluent TSS from simulated STOAT model is 17.11 ± 1.41 mg/L, and RMSD is (3.2), and NRMSD is 18.5%, as shown in Figure (5) & Table (6).

The influent TVSS from the analysis of samples for a period of three months is 129 ± 25.28 mg/L, the effluent TVSS for treated wastewater is 11.45 ± 4.10 mg/L, and the effluent TVSS from simulated STOAT model is 12.62 ± 1.10 mg/L, and RMSD is (2.1), and NRMSD is 16.8%, as shown in Figure (6) & Table (6).

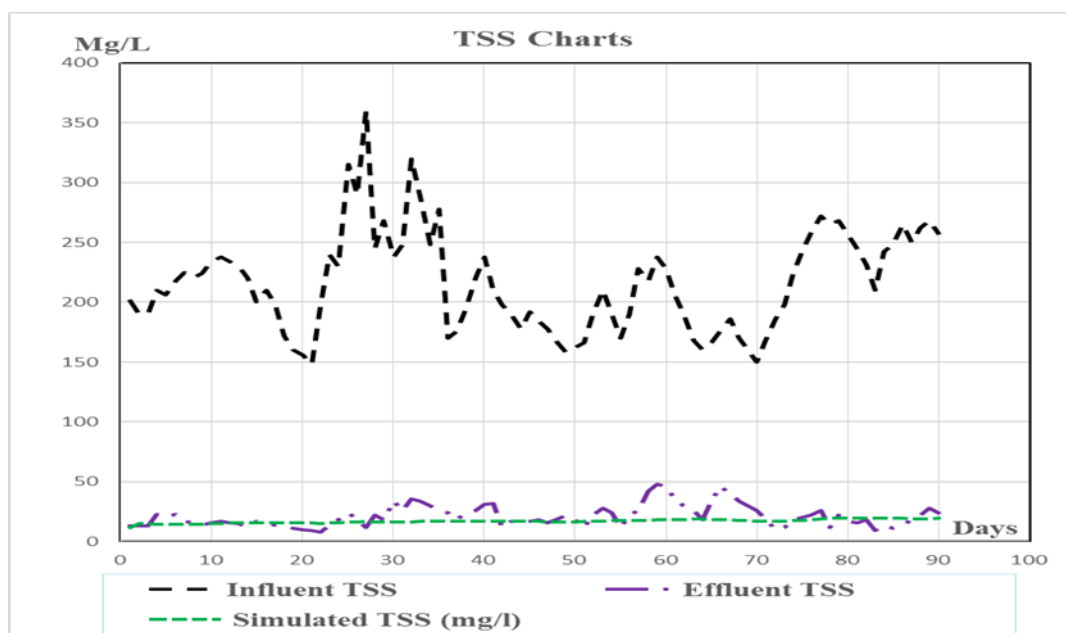


Fig. 5: Influent, effluent, and simulated effluent TSS

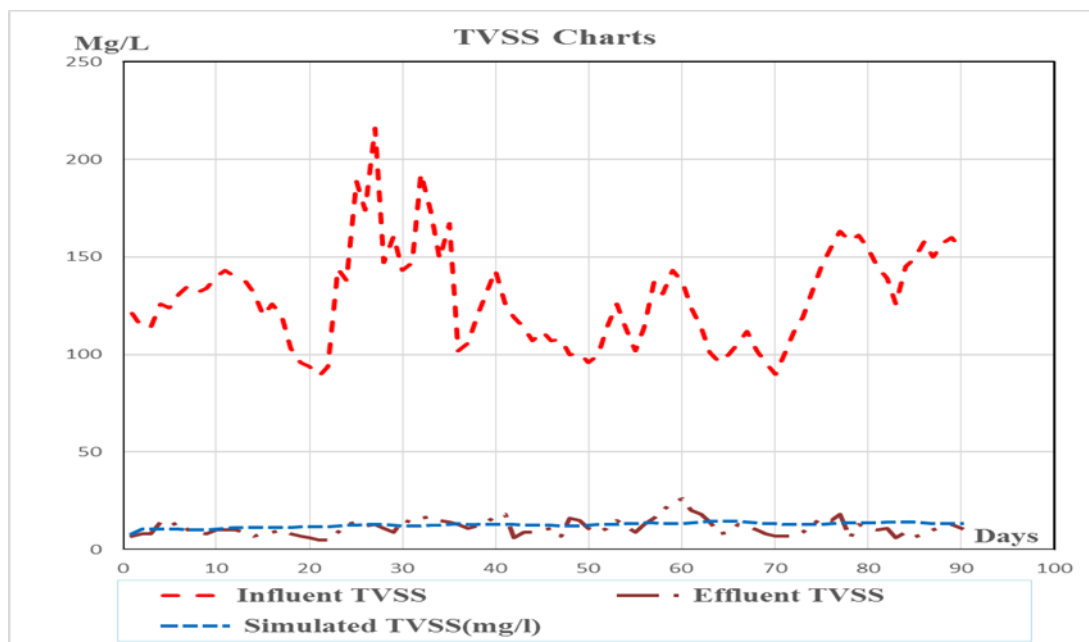


Fig. 6: Influent, effluent, and simulated effluent TVSS

3.2.3 Model validation - Dissolved oxygen (DO) analysis:

The influent DO from the analysis of samples for a period of three months is 0.24 ± 0.06 mg/L, the effluent DO for treated wastewater is 5.8 ± 0.54 mg/L, and the effluent DO from simulated STOAT model is 6.89 ± 0.35 mg/L, and RMSD is (1.2), and NRMSD is 19.5%, as shown in Figure (7) & Table (6).

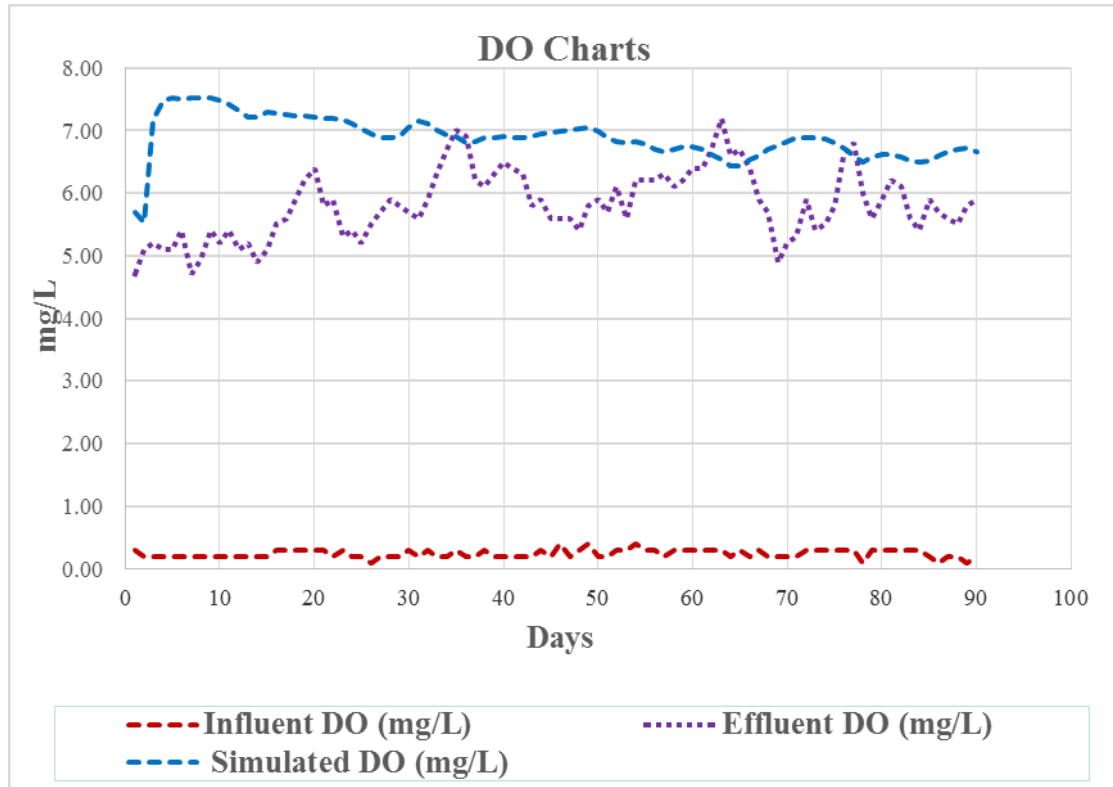


Fig 7: Influent, effluent, and simulated effluent DO.

3.2.4 Model validation - pH analysis

The influent pH from the analysis of samples for a period of three months is 6.42 ± 0.25 , the effluent pH for treated wastewater is 6.91 ± 0.2 , and the effluent pH from simulated STOAT model is 7.00 ± 0.00 , and RMSD is (0.22), and NRMSD is 3.2%, as shown in Figure (8) & Table (6).

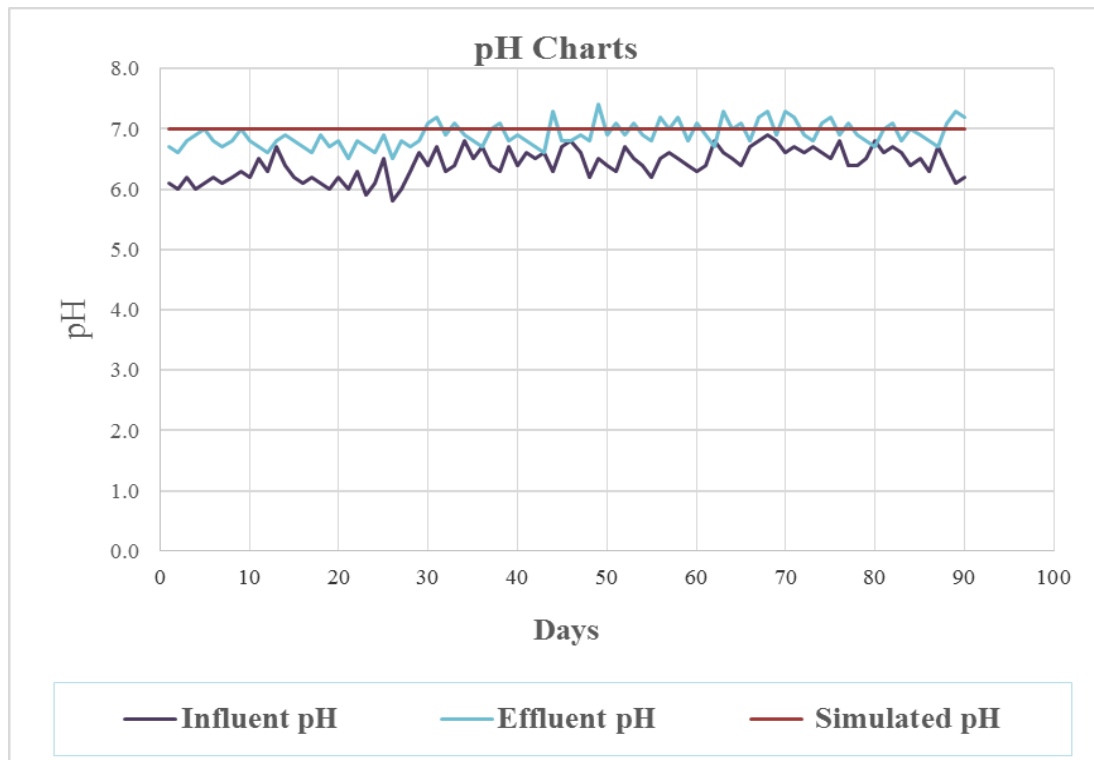


Fig 8: Influent, effluent, and simulated pH

Table 6: Comparison between Observed samples and simulated results for 10th WWTP

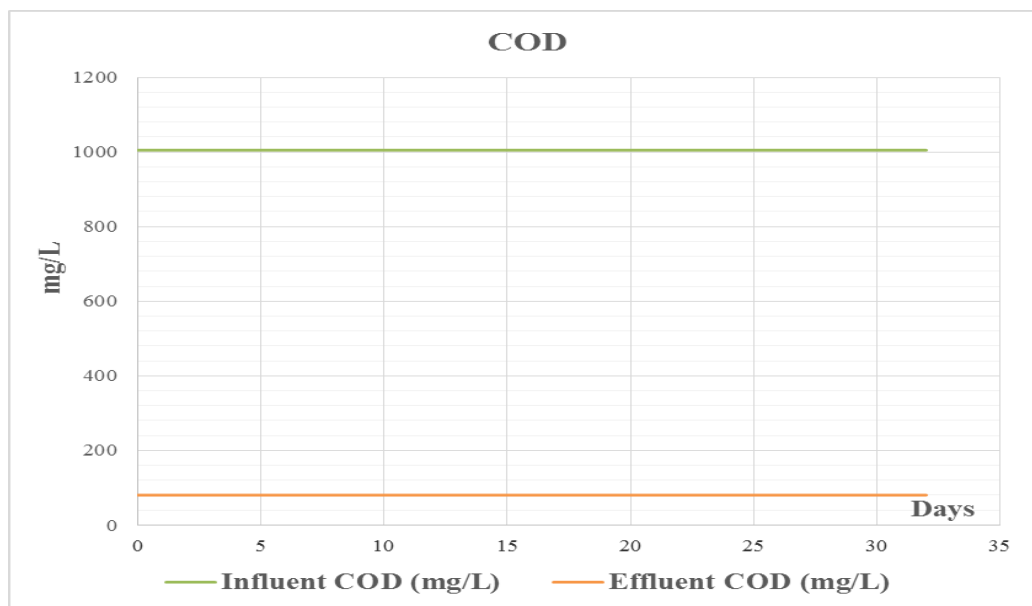
Parameter	Unit	Observed samples	Simulated results	RMSD	NRMSD
DO	mg/L	5.8 ± 0.54	6.89 ± 0.35	1.2	19.5%
pH	—	6.91 ± 0.2	7 ± 0.0	0.22	3.2%
TSS	mg/L	21.1 ± 8.93	2.72 ± 0.23	3.2	18.5%
TVSS	mg/L	11.45 ± 4.10	1.89 ± 0.19	2.1	16.8%
COD	mg/L	55.5 ± 9.86	61.11 ± 4.92	8	13.58%

Finally, it is clear from the comparison between Observed samples and simulated results for 10th WWTP, s shown in Table (6). From the statistical analysis, there is a discrepancy between the results and field samples, and the results obtained from the simulation model ranging from 13% to 20% for the variables (COD, TSS, TVSS, and DO). This indicates a discrepancy in the actual performance of the 10th of Ramadan WWTP from its ideal condition. This is likely due to some contributions from industrial facilities to the upcoming disposal of the plant.

3.3 Results and Discussion - Application of the developed model in determining capacity of the WWTP for organic loads:

Results of the simulated effluent COD, TSS, and TVSS, as well as the simulated influent DO shown in Figures (3-7) are very close with those appeared in Table (1) by difference ranges between 3 to 21%, which reflecting success and validity of the calibrated model according to Makinia et al. (2006); Liwarska-Bizukoje et al. (2013); Ayoub (2018); Jasim (2020); Elawwad (2017a, b).

After obtaining an acceptable model to simulate the performance of the WWTP plant, several hypothetical simulations of biological wastewater treatment were performed with different characteristics to obtain the maximum COD value that can be accommodated by the WWTP in its current state. As the maximum COD value of 1000 mg/L allowed in the raw wastewater so that it can be treated in the 10th of Ramadan WWTP bringing the COD value in the treated wastewater of 80 mg/L, as shown in Figure (9).

**Fig 9:** Influent maximum, and simulated effluent COD.

3.4 Results and Discussion - Sensitivity Analysis:

After obtaining a valid model to evaluate the performance of the plant wastewater treatment health, a sensitivity analysis was performed to verify the local model sensitivity to different variables during the model simulations, which lasted 90 days. Such an analysis gives the perception of the performance of the model's future performance with changing operating conditions.

A sensitivity analysis of the model was performed with the change of one of the parameters of the final sedimentation process, which is the vesilind velocity and ranges from (2, 2.5, 3, 3.5, and 4 m/s). Its effect on the final results of the plant is evident in Figures (10-13) & Table (7), whereas, all results improved with increasing the settling speed of the final tank and giving better results than opening new doors to increase research in fields of improved treatment efficiency.

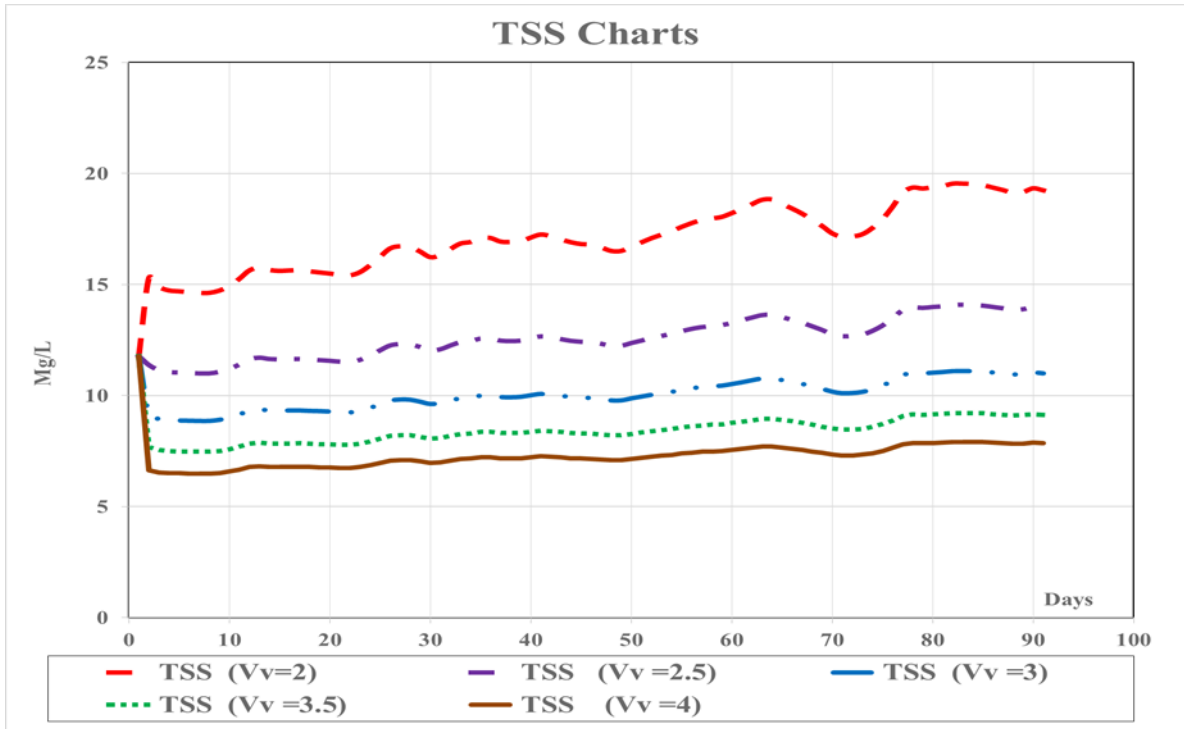


Fig. 10: TSS sensitivity analysis.

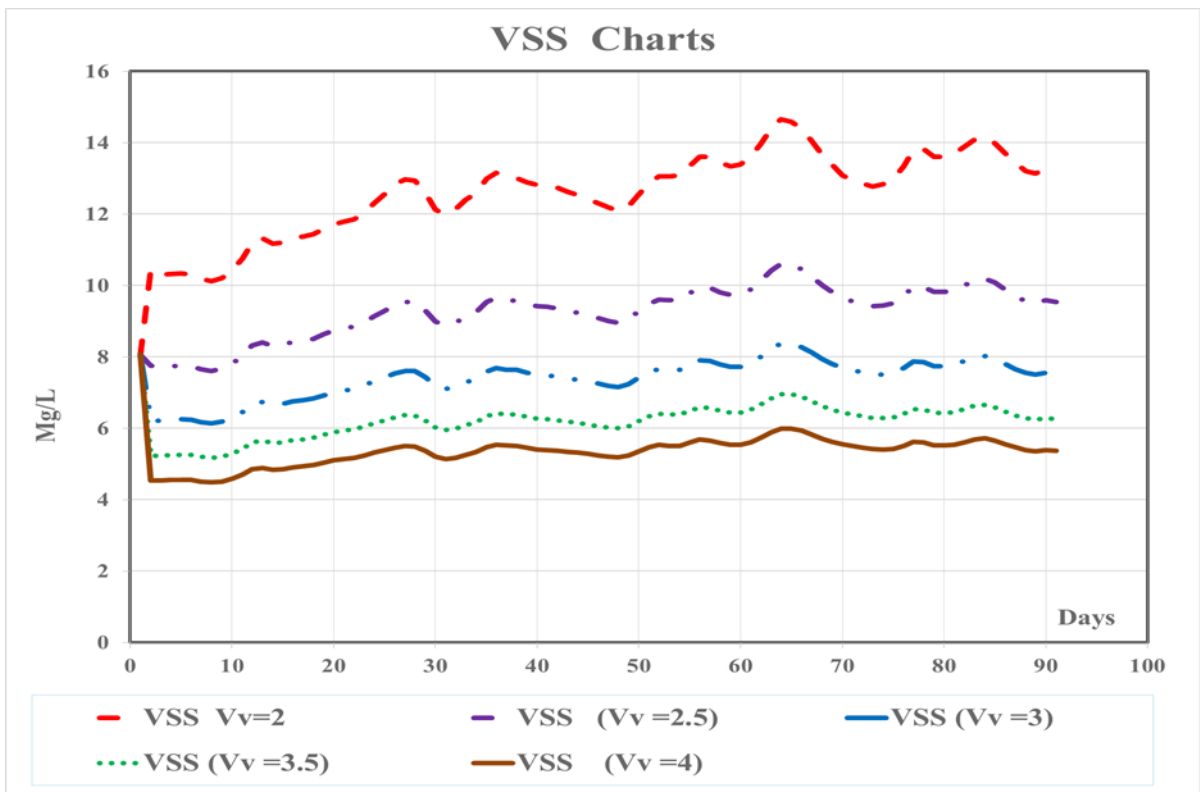


Fig. 11: VSS sensitivity analysis

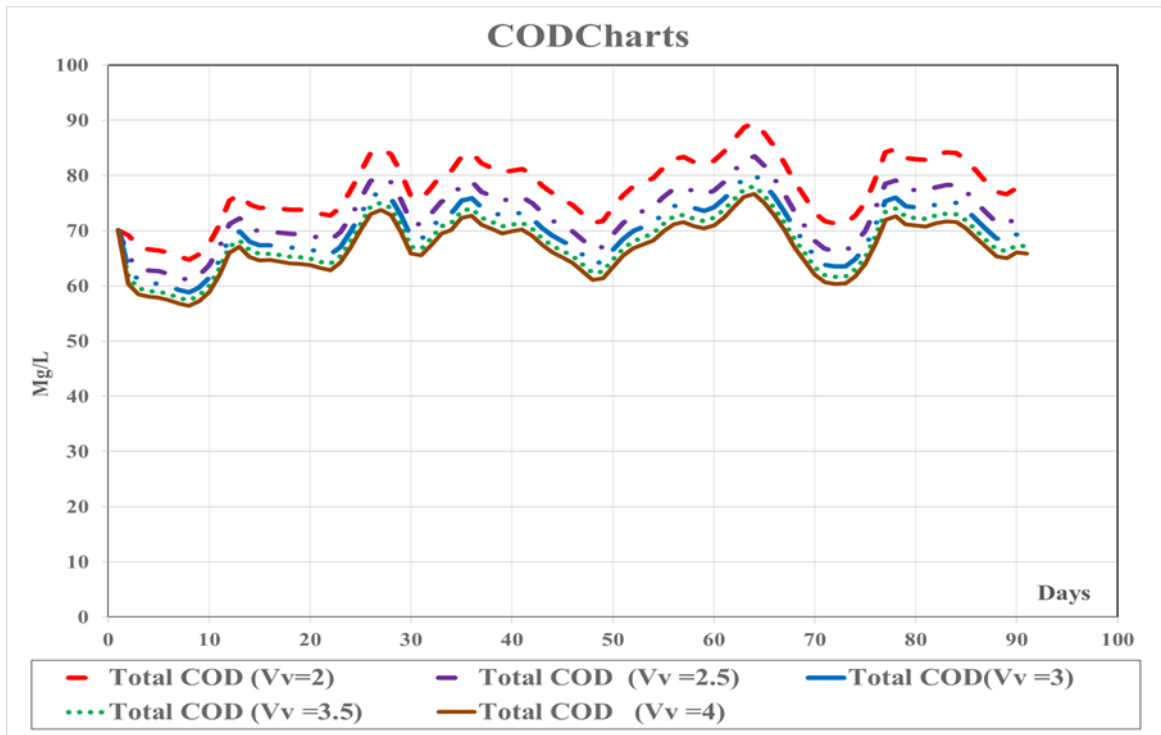


Fig. 12: COD sensitivity analysis.

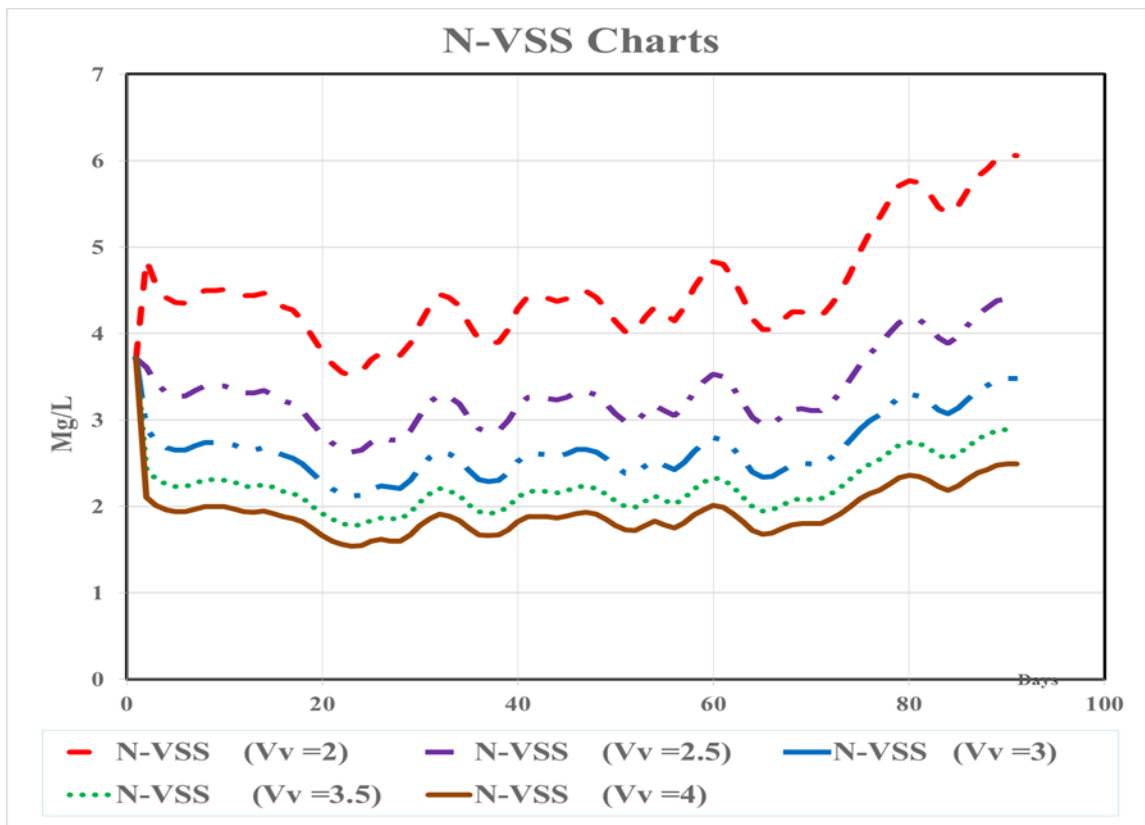


Fig.13: NVSS sensitivity analysis

Table 7: The sensitivity analysis of the model for vesilind velocity

Parameter	Vesilind Velocity = 2		Vesilind Velocity = 2.5		Vesilind Velocity = 3		Vesilind Velocity = 3.5		Vesilind Velocity = 4	
TSS	17.07	1.54	12.59	0.91	10.05	0.68	8.42	0.62	7.29	0.63
Total COD	77.62	5.82	72.70	5.27	69.92	5.03	68.14	4.90	66.89	4.82
VSS	12.57	1.23	9.26	0.75	7.39	0.55	6.19	0.48	5.35	0.46
N-VSS	4.50	0.63	3.33	0.43	2.66	0.35	2.23	0.31	1.94	0.30

CONCLUSIONS

This study revealed that applying the activated sludge model No. 1 (ASM1) via STOAT 5.0 software is valid to clarify the performance of the 10th of Ramadan City WWTP within its current status. The ASM1 model was used to simulate the performance of a full-scale of the 10th of Ramadan WWTP receiving domestic wastewater. The kinetic and stoichiometric parameters were selected to be calibrated, which are the heterotrophic rate, the aerobic endogenous respiration of heterotrophic biomass, and aerobic yield of heterotrophic biomass, which changed because of the novel variation in temperature within the plant and because of the presence of the industrial wastewater, which wasn't accounted for within the ASM1 default values. This study concluded a discrepancy between the results and field samples, and the results obtained from the simulation model ranging from 13% to 20% for the variables (COD, TSS, TVSS, and DO). This indicates a discrepancy in the actual performance of the 10th of Ramadan WWTP from its ideal condition. This is likely due to some contributions from industrial facilities to the upcoming disposal of the plant. Hence, the ASM1 model was able to describe the plant operation. Although ASM-family models including the STOAT activated sludge models were originally developed and applied to municipal wastewater, the model was demonstrated to be a good tool in predicting the performance of WWTPs with an accuracy ranging from 80% to 90%. This study expected the maximum values of COD that the plant processes without the need for any improvement processes for biological treatment.

On the other hand, during the study, some constraints were encountered, which provided recommendations for any future studies. The routinely collected data of the plant did not contain any nitrogen related measurements, as there are not any restrictions regarding nitrogen removal in Egypt until now. Therefore, it is recommended performing long-term measurements to be able to validate the model for nitrification.

REFERENCES

- Ayoub, M. (2018). Performance evaluation for the proposed upgrade of a wastewater treatment plant using ASM2d application. *International Journal of Current Engineering and Technology*, 8(5), 1303-1309.
- Barker, P. S., & Dold, P. L. (1997). General model for biological nutrient removal activated- sludge systems: model presentation. *Water Environment Research*, 69(5), 969-984.
- Di, S., Ning, T., Yu, J., Chen, P., Yu, H., Wang, J., & Zhu, S. (2020). Recent advances and applications of magnetic nanomaterials in environmental sample analysis. *TrAC Trends in Analytical Chemistry*, 115864.
- Drewnowski, J. (2019). Advanced Supervisory Control System Implemented at Full-Scale WWTP—A Case Study of Optimization and Energy Balance Improvement. *Water*, 11(6), 1218.
- Elawwad, A., Abo-Zaid, M., & Edward, M. (2017b). Plant-wide simulation for a mega WWTP: A case study of Gabal El-Asfar WWTP, Egypt. In *The International Conference of Recent Trends in Environmental Science and Engineering (RTESE'17)* (pp. 23-25).
- Elawwad, A., Zaghloul, M., & Abdel-Halim, H. (2017a). Simulation of municipal-industrial full scale WWTP in an arid climate by application of ASM3. *Journal of Water Reuse and Desalination*, 7(1), 37-44.
- Gujer, W., & Henze, M. (1991). Activated sludge modelling and simulation. *Water Science and Technology*, 23(4-6), 1011-1023.
- Gujer, W., Henze, M., Mino, T., & Van Loosdrecht, M. (1999). Activated sludge model no. 3. *Water science and technology*, 39(1), 183-193.
- Henze, M., Grady Jr, C. P. L., Gujer, W., Marais, G. V. R., & Matsuo, T. (1987). Activated sludge model No. 1. IAWPRC. In *Scientific and Technol. Report n°*. IAWPRC London.
- Henze, M. (1995). Activated sludge model No. 2. IAWQ Scientific and technical report.
- Henze, M., Gujer, W., Mino, T., & van Loosdrecht, M. C. (2000). Activated sludge models ASM1, ASM2, ASM2d and ASM3. IWA publishing.
- Hodgson, B., & Sharvelle, S. (2019). Development of generalized empirical models for comparing effectiveness of wastewater nutrient removal technologies. *Environmental Science and Pollution Research*, 26(27), 27915-27929.
- Hu, H., Shi, Y., Liao, K., Ma, H., Xu, K., & Ren, H. (2019). Effect of temperature on the characterization of soluble microbial products in activated sludge system with special emphasis on dissolved organic nitrogen. *Water research*, 162, 87-94.
- Jasim, N. A. (2020). The design for wastewater treatment plant (WWTP) with GPS X modelling. *Cogent Engineering*, 7(1), 1723782.
- Ladhari, T., Khoja, I., Msahli, F., & Sakly, A. (2019). Parameter identification of a reduced nonlinear model for an activated sludge process based on cuckoo search algorithm. *Transactions of the Institute of Measurement and Control*, 41(12), 3352-3363.
- Liawarska-Bizukojc, E., Biernacki, R. A. F. A. Ł., Gendaszewska, D., & Ledakowicz, S. T. A. N. I. S. Ł. A. W. (2013). Improving the operation of the full scale wastewater treatment plant with use of a complex activated sludge model. *Environment Protection Engineering*, 39(1), 183-195.
- Majewsky, M., Gallé, T., Bayerle, M., Goel, R., Fischer, K., & Vanrolleghem, P. A. (2011). Xenobiotic removal efficiencies in wastewater treatment plants: residence time distributions as a guiding principle for sampling strategies. *Water research*, 45(18), 6152-6162.
- Makinia, J., Rosenwinkel, K. H., & Spering, V. (2006). Comparison of two model concepts for simulation of nitrogen removal at a full-scale biological nutrient removal pilot plant. *Journal of Environmental Engineering*, 132(4), 476-487.

- Metcalf & Eddy, Burton, F. L., Stensel, H. D., & Tchobanoglous, G. (2003). Wastewater engineering: treatment and reuse. McGraw Hill.
- Mhlanga, F. T. (2016). Modelling municipal wastewater treatment plants for industrial effluent discharge permitting: focusing on how modelling can be carried out in cases where measurements and resources are limited (Doctoral dissertation).
- Panepinto, D., Riggio, V., Ruffino, B., Campo, G., Cerutti, A., Borzooei, S. ... & Zanetti, M. C. (2020). Optimization of the Wastewater Treatment Plant: From Energy Saving to Environmental Impact Mitigation. In *Frontiers in Water-Energy-Nexus—Nature-Based Solutions, Advanced Technologies and Best Practices for Environmental Sustainability* (pp. 231-233). Springer, Cham.
- Pasztor, I., Thury, P., & Pulai, J. (2009). Chemical oxygen demand fractions of municipal wastewater for modeling of wastewater treatment. *International Journal of Environmental Science & Technology*, 6(1), 51-56.
- Rice, E. W., Baird, R. B., Eaton, A. D., & Clesceri, L. S. (2012). *Standard Methods For the Examination of Water and Wastewater*. Part, 2540, 2-66.
- Rieger, L., Gillot, S., Langergraber, G., Ohtsuki, T., Shaw, A., Takács, I., & Winkler, S. (2012). Guidelines for using activated sludge models. IWA Task Group on Good Modelling Practice. IWA Scientific and Technical Report.
- Sin, G. (2004) Systematic calibration of activated sludge models. PhD. Thesis, Faculty of Agricultural and Applied Biological Sciences, Ghent University, Belgium.
- Šikić, T., Welles, L., Rubio-Rincón, F. J., Matošić, M., & Brdjanovic, D. (2019). Assessment of Enhanced Biological Phosphorus Removal Implementation Potential in a Full-Scale Wastewater Treatment Plant in Croatia. *International Journal of Environmental Research*, 13(6), 1005-1013.
- Tian, T., Zhou, K., Xuan, L., Zhang, J. X., Li, Y. S., Liu, D. F., & Yu, H. Q. (2020). Exclusive microbially driven autotrophic iron-dependent denitrification in a reactor inoculated with activated sludge. *Water research*, 170, 115300.
- Von Sperling, M., 2007. *Wastewater Characteristics, Treatment and Disposal: Biological Wastewater Treatment Series Volume 1*. Published by IWA Publishing, ISBN 1843391619, 9781843391616, 308 pp.
- WRc PLC. (2012). *Dynamic Modeling of Wastewater Treatment Plants*. stoat@wrcplc.co.uk.
- Zeng, M., Soric, A., & Roche, N. (2013). Calibration of hydrodynamic behavior and biokinetics for TOC removal modeling in biofilm reactors under different hydraulic conditions. *Bioresource technology*, 144, 202-209.