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Research Article

Performance evaluation for the proposed upgrade of a wastewater treatment plant using ASM2d application

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Abstract

The activated sludge models (ASM) group has been created by IWA task group to facilitate a deep understanding of the activated sludge systems in wastewater treatment. The present study aims to assess validation of activated sludge model No. 2d (ASM2d) after being calibrated under conditions of the wastewater treatment plant (WWTP). The present study confirmed that applying the activated sludge model No. 2d (ASM2d) via computer-aided software is valid to describe the performance of WWTP in the current status, which suffers from the inadequacy of the treatment outputs to some extent with the standard specifications of reusing the treated wastewater for agricultural irrigation purposes. Furthermore, the calibrated ASM2d for conditions of the WWTP can be utilized to upgrade the integrated treatment system for enhancing the treatment quality in accordance with the permitted level of standard specifications of irrigation purposes.

Keywords: *Activated sludge, ASM, modelling, simulation, upgrade, wastewater treatment*

1. Introduction

The activated sludge system has almost become the preferred choice for most designers and operators of wastewater treatment systems because of its efficient treatment, economic effectiveness, and environmental safety (Metcalf & Eddy, 2003; Soliman *et al*., 2015; Elawwad *et al*., 2017a; Elawwad *et al*., 2017b). In this system, the biodegradable organics and nutrients are consumed using suspended microorganisms in the precise operational conditions. However, changing in the wastewater characteristics influences directly on activated sludge performance and results a lower effluent quality as compared to the standard specifications for the treated wastewater quality. Therefore, wastewater treatment plants need to be modeled and simulated to analyze the treatment processes under varying circumstances (Metcalf & Eddy, 2003; Nasr *et al*., 2011; El-Monayeri, 2016; Gao *et al*., 2016; Elawwad *et al*., 2017a).

Dynamic simulation facilitates a deep understanding of wastewater treatment processes based on the mathematical modelling (Henze *et al*., 2000; Langergraber *et al*., 2004;WEF, 2013; Elawwad *et al*., 2017a). The mathematical models have been applied in design, optimization, and performance evaluation of the activated sludge systems to reduce the differences between modelling the output results and real treatment results (Soliman *et al*., 2015; Salem *et al*., 2002).The activated sludge model (ASM) is the well-known model in this field. The ASM group has been created by IWA task group (Henze *et al*., 1987;Henze *et al*., 2000; Langergraber *et al*., 2004; James *et al*., 2015;Elawwad *et al*., 2017a; Elawwad *et al*., 2017b; Hvala *et al*., 2017; Sabri *et al*., 2017).

The activated sludge model No.1 (ASM1) has been applied for dynamic simulation of the organic matter degradation as well as the nitrification and denitrification processes (Henze *et al*., 2000; Soliman *et al*., 2015). For more in-depth modelling of biological phosphorus removal, the activated sludge models No.2, No.2d (ASM2, ASM2d) were developed. ASM2d is distinguished from ASM2 with including of denitrifying the phosphorus-accumulating organisms in addition to the temperature dependent. Therefore, ASM2d appropriates demonstrating of carbon degradation, nitrification, denitrification, and phosphorus removal (Henze *et al*., 1995; Henze *et al*., 1999; Henze *et al*., 2000). On the other hand, the activated sludge model No.3 (ASM3) was developed in 1999 to be a new standard for future modelling (Henze *et al*., 2000; Elawwad *et al*., 2017a).

Elawwad *et al*. (2017a) evaluated the ASM3 for performance simulation of 6th October WWTP in a semi-arid climate in Egypt. The ASM3 resulted good correlations with measurements of chemical oxygen demand (COD), total suspended solids (TSS), and mixed liquor suspended solids (MLSS) concentrations.

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However, nitrification process requires to be modelled in the same climate conditions (Elawwad *et al*., 2017a). Calibration and validation of the model have a direct impact on the simulation efficiency in addition to accuracy of the results. There are three kinetic and stoichiometric parameters in calibration, which are the maximum heterotrophic growth rate, the aerobic endogenous respiration of heterotrophic biomass, and aerobic yield of heterotrophic biomass. Furthermore, the validation aims to confirm the model calibration with an independent set of performance data from a short span period (Henze *et al*., 1999; Hulsbeek *et al*., 2002; Langergraber *et al*., 2004; Elawwad *et al*., 2017a). These processes can be performed using computer-aided software to facilitate the design and performance optimization of the wastewater treatment plants. The most regularly used software are STOAT, GPS-X, WEST, SIMBA, BioWin. STOAT (Sewage Treatment Operation and Analysis for Time) is free of charge software produced by the PLC WRc Company, which can be used to simulate individual treatment processes or the integrated treatment systems. Moreover, STOAT enables both BOD_5 and COD modelling, in addition to offer new models continuously in each update of the program. For example, chemical phosphorus removal and chemically enhanced primary treatment (CEPT) were included in STOAT 5.0 (WRc, 2012; Al-Shahwan *et al*., 2016; Gao *et al*., 2016).

Effectiveness of the chemically enhanced primary treatment (CEPT) of wastewater has been demonstrated to be a proficient technique to remove about 90% of TSS, 60% of BOD_5, 60% of COD, 90% of total phosphorus (TP), and 25% of total nitrogen (TKN). These achievable removals of pollutants enable upgrading of wastewater treatment plants via reducing the organic loads on biological treatment or accommodate excess organic load on primary sedimentation. In general, quality of the treated wastewater can be improved in the final effluent (Ødegaard, 1989; Metcalf & Eddy, 2003; Rashed *et al*., 2013; Ayoub *et al*., 2017).

This study aims to assess validation of ASM2d after being calibrated in the current status of Ghazl El-Mahalla WWTP located in El-Mahalla El-Koubra City, Egypt. Furthermore, the calibrated ASM2d is then used to evaluate the proposed upgrading of WWTP using CEPT technique.

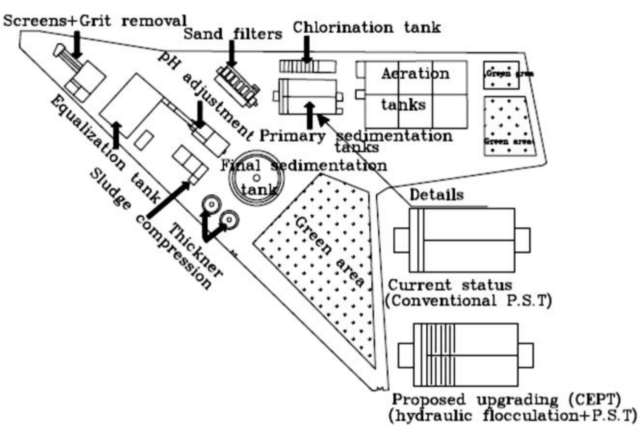
2. Methodology

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

2.1 Study area

Ghazl El-Mahalla WWTP shown in figure (1) is located in El-Mahalla El-Koubra City, El-Gharbia Governorate, about 130 km north Cairo, Egypt. The WWTP receives industrial wastewater from Misr Spinning and Weaving Company in addition to domestic wastewater from a residential compound of the company to treat 50000 m^3/d of wastewater. The preliminary treatment begins with the entry of raw wastewater into the screens and the grit removal chamber. Then wastewater is pumped from collection tank to the equalization tank to ensure full homogeneity and stability of wastewater characteristics as much as possible. Subsequently, wastewater passes through a Venechury meter channel to the neutralization tank for pH adjustment by adding the sulfuric acid or sodium hydroxide. Then, wastewater flows to the primary sedimentation tanks followed by aeration tanks (activated sludge system) and final sedimentation tank to be secondary treated. The secondary treated wastewater enters to chlorination tank for disinfection followed by sand filters to be tertiary treated for reuse. On the other hand, the sludge processing system is completed by collecting the primary sludge from the primary sedimentation tanks and the excess sludge from the final clarifiers to the sludge thickeners and then to the sludge compression machine (CSMSWC, 2017).

The treated wastewater is used in irrigation of the green areas and sometimes its quality does not meet the standard specifications for reuse of the treated wastewater. Therefore, it is proposed to upgrade the WWTP based on CEPT technique, where the conventional primary sedimentation tanks are modified to become hydraulic clari-flocculators divided into hydraulic flocculator by horizontal baffles and the rest of the tank for sedimentation as shown in details of the figure (1). Alum was considered to be inline mixed as a coagulant (Ayoub *et al*., 2013; Ayoub *et al*., 2017).



(a)

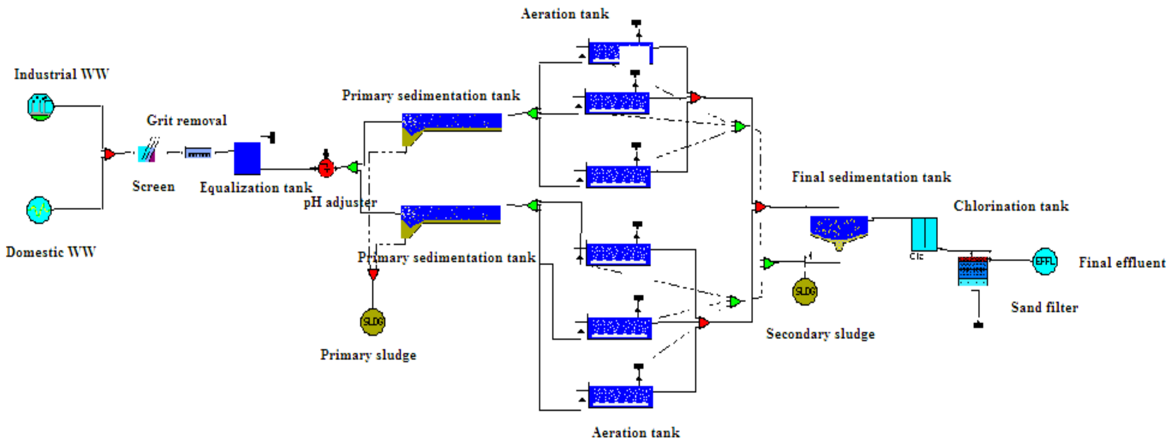
(b)

Fig.1 Ghazl El-Mahalla WWTP in (a) a general layout showing the current status and the proposed upgrading, (b) an aerial photo adapted from Google Earth, March 2018

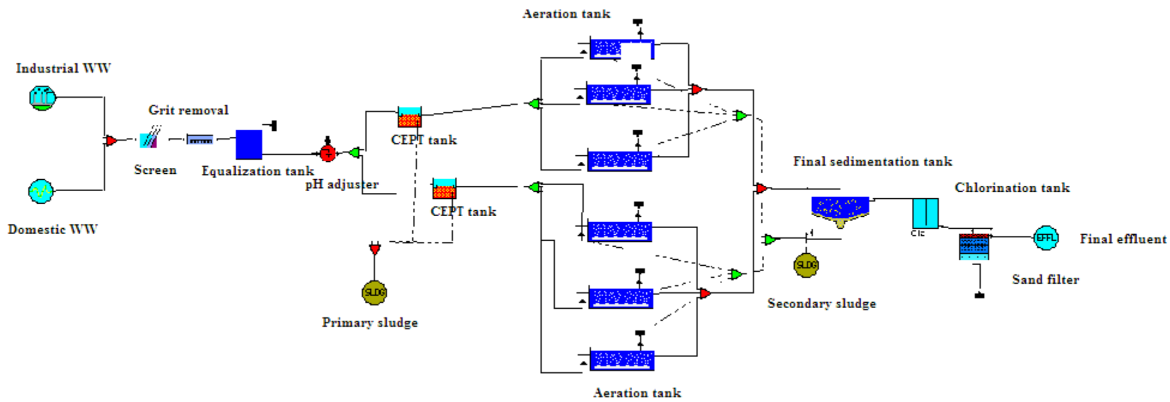
2.2 Model development of Ghazl El-Mahalla WWTP

Model development and simulation of Ghazl El-Mahalla WWTP was completed as shown in figure (2) using STOAT 5.0 software by WRc plc. Figure (2-a) represents a configuration of Ghazl El-Mahalla WWTP in the current status including, screens, grit removal chamber, equalization tank, pH adjustment, primary sedimentation tanks, aeration (biological treatment) tanks, final clarifier, chlorination tank, and finally sand filters. In this manner, the ASM2d was selected for simulating the biological treatment tanks for a compelling expression of carbon degradation, nitrification, denitrification, and phosphorus removal as indicated by Henze *et al*. (2000).

After model calibration and validation, the model of Ghazl El-Mahalla WWTP was altered by replacing the conventional primary sedimentation tanks by CEPT tanks (hydraulic clari-flocculators) as shown in figure (2-b) and proposed for upgrading as appeared in figure (1-a). Then, the proposed upgrading of Ghazl El-Mahalla WWTP can be evaluated by comparing the treated wastewater characteristics (outputs from STOAT 5.0) with the permissible limits according to the standard specifications of the tertiary treated wastewater for reusing in agricultural irrigation purposes.



(a)



(b)

Fig.2 Modelling of Ghazl El-Mahalla WWTP in (a) the current status, (b) the proposed upgrading, by STOAT 5.0 software

2.3 The operational parameters and wastewater characteristics

Results of the operational parameters and wastewater characteristics of Ghazl El-Mahalla WWTP were collected in the steady-state during the period from October 2016 to September 2017 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. It is observed that mean values of the effluent BOD_5, COD, and TSS exceed those permitted limit for irrigation purpose, which means that the current status of Ghazl El-Mahalla WWTP needs to be upgraded to produce treated wastewater conformed with the Standard Specifications of irrigation water (AbuZeid and Elrawady, 2014).

Table 1 The wastewater characteristics of Ghazl El-Mahalla WWTP (CSMSWC, 2017)

Parameter	Influent (Raw wastewater)	Final effluent (Treated wastewater)	Limits for irrigation*
pH	10.8 ± 0.4	7.9 ± 0.5	6-9
Temperature (º C)	35 ± 4	-	-
TDS (mg/L)	1250 ± 112	1060 ± 83	2000
BOD_5 (mg/L)	460 ± 63	30 ± 7.8	20
COD (mg/L)	1100 ± 193	89 ± 14	40
TSS (mg/L)	466 ± 82	21 ± 5.4	20
Ammonium, NH_4 (mg/L)	11.1 ± 1.3	-	5
Nitrate, NO_3 (mg/L)	3.5 ± 0.6	-	10
Phosphate, PO_4 (mg/L)	18.3 ± 3.7	-	-

*Notes: Adapted from AbuZeid and Elrawady (2014)

Table 2 The operational parameters of Ghazl El-Mahalla WWTP

Parameter	Average value	Design criteria*
Aeration period (θ) (hr)	9.33	4-8
Mean cell residence time (θ_c) (day)	10	3-15
Mixed liquor suspended solids (MLSS) (mg/L)	2503	1000-3000
Mixed liquor volatile suspended solids (MLVSS) (mg/L)	1835	-
Food/Mass of microorganisms (F/M) (Kg BOD_5/Kg MLSS)	0.3	0.2-0.4
Volumetric loading rate (V_L) (Kg $BOD_5/m^3.d$)	0.828	0.3-0.7
Return activated sludge (RAS) flow (m^3/d)	20000	-
Return activated sludge (RAS) concentration (mg/L)	8517	-
Return activated sludge (RAS) ratio (%)	40	-
Wasted activated sludge (WAS) flow (m^3/d)	571.3	-
Mass of solids produced (Kg /d)	4866	-

*Notes: Design criteria for the conventional activated sludge system adapted from Metcalf and Eddy (2003)

A sampling collection system was completed more carefully and intensively during ten days of October 2017 for measurements of the different wastewater parameters. These results were also statistically investigated to obtain the mean values and standard deviations for each parameter as shown in table (3). All analyses were conducted according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2012).

Table 3 The wastewater characteristics of Ghazl El-Mahalla WWTP during the sampling collection period for model calibration

Parameter	Influent	Final effluent
pH	10.2 ± 0.3	7.9 ± 0.5
Temperature (º C)	32 ± 3	-
BOD_5 (mg/L)	390 ± 50	34 ± 5.9
COD (mg/L)	860 ± 126	73 ± 11
TSS (mg/L)	415 ± 67	20 ± 6.5
Ammonium, NH_4 (mg/L)	9.8 ± 1.5	-
Nitrate, NO_3 (mg/L)	4.5 ± 0.8	-
Phosphate, PO_4 (mg/L)	19.6 ± 4.7	-

3. Results and discussion

3.1 Model calibration

The current status of Ghazl El-Mahalla WWTP has been simulated using ASM2d for modelling the biological treatment with its default values of the kinetic and stoichiometric parameters in STOAT 5.0 software. According to Henze *et al*. (1999), Hulsbeek *et al*. (2002), Langergraber *et al*. (2004), Elawwad *et al*. (2017a), 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 least difference between the measured and simulated values of wastewater characteristics.

The calibrated values of maximum growth rate of the heterotrophic biomass (μ_H), the endogenous decay rate of the heterotrophic biomass (b_H), and yield of the heterotrophic organisms (Y_H) were 7.2 d^{-1}, 0.5 d^{-1}, and 0.45 respectively, instead of their default values, which are 6 d^{-1}, 0.4 d^{-1}, and 0.63 correspondingly as indicated by Henze *et al*. (2000).

3.2 Model validation

The current status of Ghazl El-Mahalla WWTP was simulated based on the calibrated ASM2d of the aeration tanks and the operational and wastewater parameters appeared in tables (1) and (2) in order to evaluate the validity of the calibrated model. Figure (3) represents the analytical results of BOD_5, COD, and TSS for the influent and final effluent of Ghazl El-Mahalla WWTP in addition to the simulated effluent generated by STOAT 5.0 software and finally the allowable limits in the reuse of treated wastewater for irrigation purposes (AbuZeid and Elrawady, 2014).

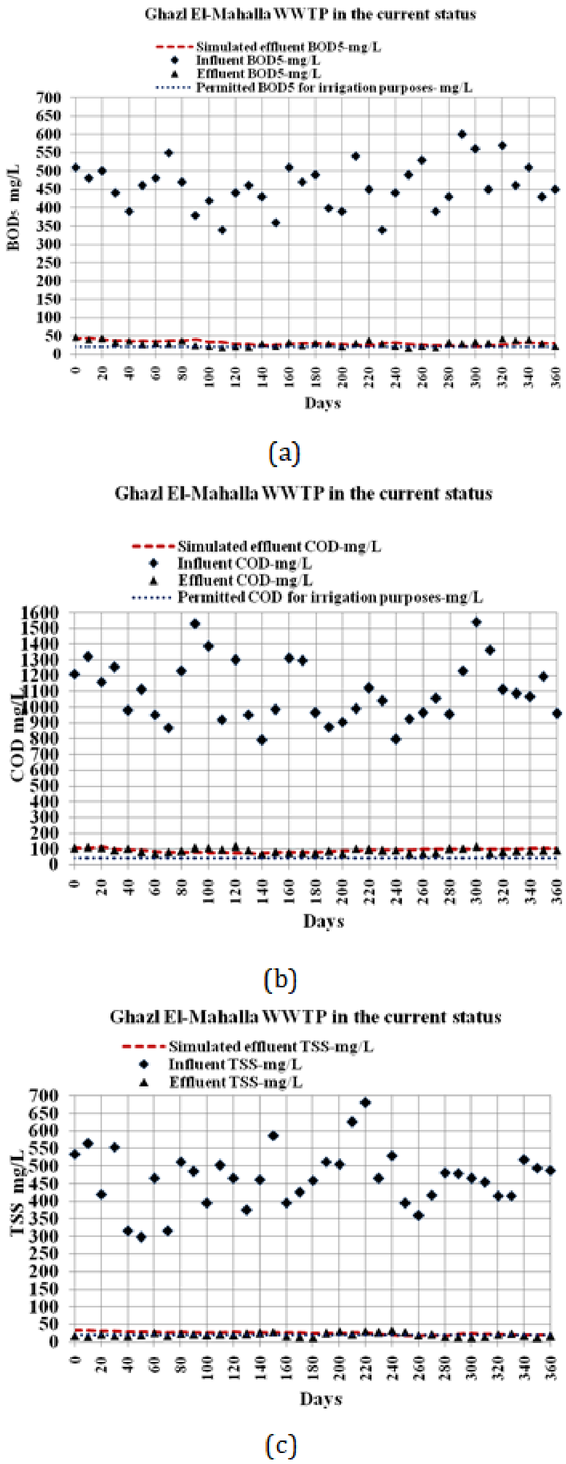
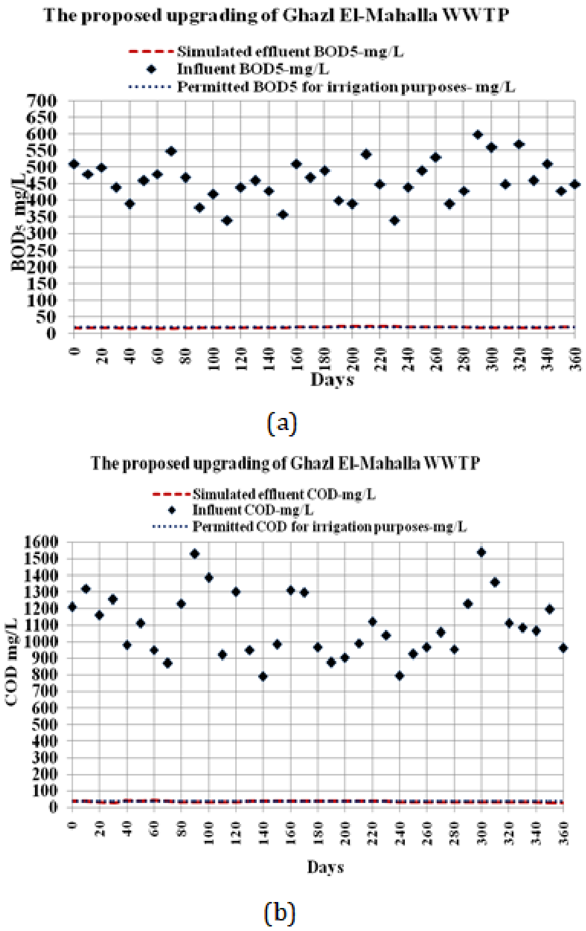


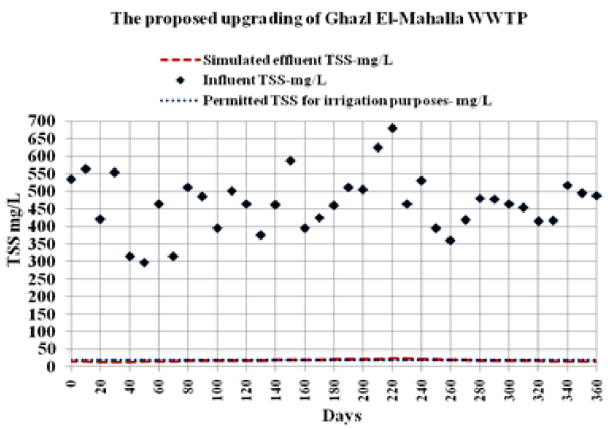
Fig.3 The analytical, simulated, and permitted limit values of (a) BOD_5, (b) COD, (c) TSS for the current status of Ghazl El-Mahalla WWTP

Comparing results of the effluent BOD_5, COD, and TSS shown in figure (3) with those permitted values for irrigation purposes revealed that the treated wastewater quality is not validated for irrigation purposes in the current status according to AbuZeid and Elrawady (2014). On the other hand, the various results of effluent BOD_5, COD, and TSS generated from the simulation were also statistically analyzed to get the mean values and standard deviations for each parameter as 30 ± 5.9 for BOD5, 90 ± 12 for COD, and 25 ± 4.2 for TSS. These values are very close with those resulting from the statistical analysis as appeared in table (1) by a difference of between 6 to 19% and in all cases less than 20%, which reflecting success and validity of the calibrated model according to Makinia *et al*. (2006); Liwarska-Bizukojc *et al*. (2013); and Elawwad (2017).

3.2 Evaluation of the proposed upgrading of Ghazl El-Mahalla WWTP

The proposed upgrading of Ghazl El-Mahalla WWTP was modelled as shown in figure (2-b) by replacing the conventional primary sedimentation tanks with CEPT tanks, in addition to apply the calibrated ASM2d model for biological treatment. The average parameters of raw wastewater were used in the characterization of initial conditions in STOAT 5.0 software. Moreover, the simulated results of the effluent quality were compared with the permitted limits for irrigation purposes as represent in figures (4) and (5).The average values of the simulated effluent BOD_5, COD, TSS, are 19, 35, and 18 mg/L, respectively, while those permitted limits for irrigation purposes are 20, 40, and 20 mg/L as shown in figures (4-a), (4-b), and (4-c) in that order, according to AbuZeid and Elrawady (2014) reflecting the successful treatment in the proposed upgrading.

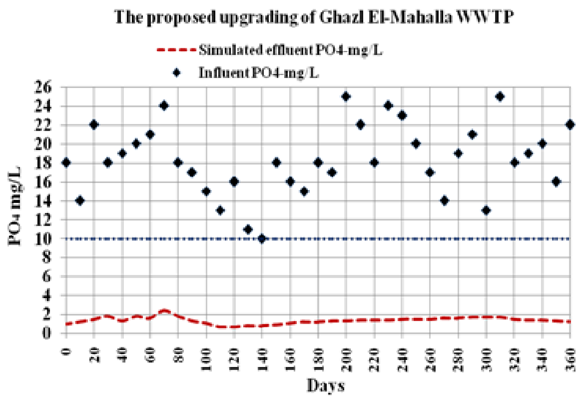




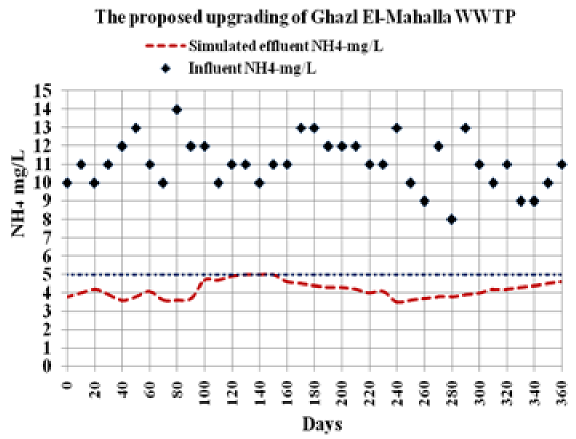
(c)

Fig.4 The influent, simulated effluent, and permitted limit values of (a) BOD_5, (b) COD, (c) TSS for the proposed upgrading of Ghazl El-Mahalla WWTP

Likewise, the nutrients removal can be investigated from figure (5). It is noticed that the average values of the effluent PO_4, NH_4, and NO_3 are 1.4, 4.2, and 2.2 mg/L respectively. Therefore, these values are well below the acceptable limits of PO_4, NH_4, and NO_3 for the irrigation purposes, which are 10, 5, 10 mg/L correspondingly according to AbuZeid and Elrawady(2014) reflecting the successful treatment in the proposed upgrading.



(a)



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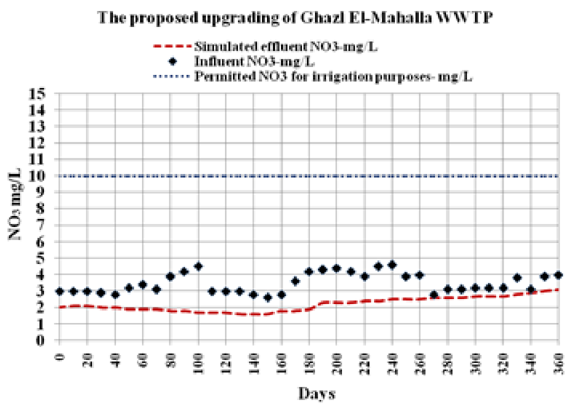

(c)

Fig.5 The influent, simulated effluent, and permitted limit values of (a) PO_4, (b) NH_4, (c) NO_3 for the proposed upgrading of Ghazl El-Mahalla WWTP

From the previous results, the CEPT of wastewater is an effective approach for upgrading Ghazl El-Mahalla WWTP to develop the current status and achieve treated wastewater quality for sustainable reusing in the agricultural irrigation purposes, which has been demonstrated using the calibrated ASM2d via STOAT 5.0 software.

Conclusions

The present study revealed that applying the activated sludge model No. 2d (ASM2d) via STOAT 5.0 software is valid to describe the performance of Ghazl El-Mahalla WWTP in the current status, which suffers from the inadequacy of the treatment outputs to some extent with the standard specifications of reusing the treated wastewater for agricultural irrigation purposes. Furthermore, the calibrated ASM2d for conditions of Ghazl El-Mahalla WWTP can be utilized to upgrade the integrated treatment system for enhancing the treatment quality in accordance with the permitted level of standard specifications of irrigation purposes.

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References

AbuZeid, K; Elrawady, M. (2014).*Strategic Vision for Treated Wastewater Reuse in Egypt*. Water Resources Management Program, CEDARE.

Al-Shahwan, A.A; Balhaddad, A.M.S; Al-Soudani, H.H.O; Nuhu, D.M; and Abdel-Magid, I.M. (2016).Municipal wastewater treatment plants monitoring and evaluation: Case study Dammam Metropolitan Area. *Advance Research Journal of Multi-Disciplinary Discoveries*, 1(1): 1-9.

APHA (2012).*Standard Methods for the Examination of Water and Wastewater*. 22nd edition. APHA, AWWA, and WEF, Washington.

Ayoub, M; Afify, H; and Abdelfattah, A. (2017).Chemically enhanced primary treatment of sewage using the recovered alum from water treatment sludge in a model of hydraulic clari-flocculator. *Journal of Water Process Engineering*, 19(July): 133-138.

Ayoub, M; El-Morsy, A; and Rashed, I.G. (2013).Hydraulic clari-flocculation for chemically enhanced primary treatment of sewage. *The 17th International Water Technology Conference*, 5–7 November 2013, Istanbul, Turkey.

CSMSWC.(2017). Construction Sector in Misr Spinning & Weaving Company. Egypt.

Elawwad, A. (2017). Optimized biological nitrogen removal of high-strength ammonium wastewater by activated sludge modeling. *Journal of Water Reuse and Desalination*, (In press).

Elawwad, A; Zaghloul, M; and 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.

Elawwad, A; Abo-Zaid, M; and Edward, M. (2017b).*Plant-wide simulation for a mega WWTP: A case study of Gabal El-Asfar WWTP, Egypt*. The International Conference of Recent Trends in Environmental Science and Engineering (RTESE'17), 23-25 August, Toronto, Canada, Paper No. 139.

El-Monayeri, O.D. (2016).Comparative study to assess the performance of an integrated treatment system using ANN vs. GPS-X .*International Journal of Applied Engineering Research*, 11(8): 5604-5609.

Gao, Y.N; Liu, X.Z; Zhang, R.X; Shan, J.J; Sun, M.Q; Zong, Z.X; Li, C.W; and Wang, X.Z. (2016). *Operation and management of Liaoning wastewater treatment plants by STOAT simulation*. MATEC Web of Conferences 63, 04019.

Henze, M; Grady, C.P.L; Gujer, W; Marais, G.V.R; and Matsuo, T . (1987). *Activated Sludge Model No.1, IAWPRC Scientific and Technical Report No.1*. International Association on Water Pollution Research and Control, London, UK.

Henze, M; Gujer, W; Mino. T; and Van Loosdrecht, M.C.M. (2000).*Activated Sludge Models ASM1, ASM2, ASM2d and ASM3. IWA Scientific and Technical Report No.9*.IWA Publishing, London, UK.

Henze, M; Gujer, W; Mino.T; Matsuo, T; Wentzel, M.C; and Marais, G.V.R. (1995).*Activated Sludge Model No.2*, IAWQ Scientific and Technical Report No.3.International Association on Water Quality, London, UK.

Henze, M; Gujer, W; Mino.T; Matsuo, T; Wentzel, M.C; Marais, G.V.R; and Van Loosdrecht, M.C.M. (1999).Activated Sludge Model No.2D, ASM2D.*Water Science and Technology*, 39(1): 165-182.

Hvala, N; Vrečko, D; Levstek, M; and Bordon, C. (2017). The use of dynamic mathematical models for improving the designs of upgraded wastewater treatment plants. *Journal of Sustainable Development of Energy, Water and Environment Systems* , 5(1): 15-31.

Hulsbeek, J.J.W; Kruit, J; Roeleveld, P.J; and Van Loosdrecht, M.C.M (2002).A practical protocol for dynamic modelling of activated sludge systems. *Water Science and Technology*, 45(6): 127-136.

James, O.O; Jiashun, C; Qian, F; Gan, W; Zhaoxia, X; and Fang, F. (2015). Evaluation and improvement of wastewater treatment plant performance using BIOWING*.*Chinese Journal of Oceanlogy and Limnology*, 33(2): 468-476.

Langergraber, G; Rieger, L; Winkler, S; Alex, J; Wiese, J; Owerdieck, C; Ahnert, M; Simon, J; and Maurer, M. (2004). A guideline for simulation of wastewater treatment plants. *Water Science and Technology*, 50(7): 131-138.

Liwarska-Bizukojc, E; Biernacki, R; Gendaszewska, D; and Ledakowicz, S. (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.

Makinia, J; Rosenwinkel, K.H; and 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 and Eddy, Inc., Tchobanoglous, G; Burton, F.L; Stensel, H.D. (2003).*Wastewater Engineering Treatment and Reuse*.4th edition, McGraw-Hill, New York.

Nasr, M; Moustafa, M.A.E; Seif, H.A.E; and ElKobrosy, G. (2011). Modelling and simulation of German BIOGEST/ EL-AGAMY wastewater treatment plants- Egypt using GPS-X simulator .*Alexandria Engineering Journal*, 50(4): 351-357.

Ødegaard, H. (1989). *Chemical Wastewater Treatment–Value for Money*. in Hahn, H. and Klute, R. (Eds), Chemical Water and Wastewater Treatment, Springer Verlag, Berlin.

Rashed, I.G; Afify, H.A; Ahmed, A.E; and Ayoub, M. A. (2013).Optimization of chemical precipitation to improve the primary treatment of wastewater. *Desalination and Water Treatment*, (51), Issue (37-39), p.p. 7048-7056.

Rieger, L; Gillot, S; Langergraber, G; Ohtsuki, T; Shaw, A; Takacs, I; and Winkler, S. (2012). *Guidelines for Using Activated Sludge Models, TWA Scientific and Technical Report No. 22*. IWA Publishing, London.

Sabri, D; Yassine, D; Yahia, H; and Dounia, M. (2017). Dynamic simulation of wastewater treatment plants management: Case of Souk-Akhras region, north eastern Algeria. *Journal of Water and Land Development*, 34(7-8): 221-231.

Salem, S; Berends, D; Heijnen, J.J; Alex, J; and Van Loosdrecht, M.C.M (2002).Model-based evaluation of a new upgrading concept of N-removal. *Water Science and Technology*, 45(6): 169-176.

Soliman, M.F; Dardear, M.S; Ali, N.A; Gutub, S.A; Bassyouni, M; and Soltan, M.A. (2015).*Evaluation and optimizing the operating system of aeration tanks*. International Conference on Chemical, Environmental and Biological Sciences (CEBS-2015), 18-19 March, Dubai, U.A.E, pp. 72-76.

WEF.(2013). *Wastewater Treatment Process Modeling*. Second Edition (MOP31) (WEF Manual of Practice).2nd Edition. Water Environment Federation, Virginia, USA.

WRc PLC. (2012). *Dynamic Modeling of Wastewater Treatment Plants*.stoat@wrcplc.co.uk.