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Original Article

Evaluation of Existing WWTP using GPS-X Modelling and Simulation Software

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Abstract *- Research on ways to make WasteWater Treatment Plants (WWTPs) work better is still limited. In this study, GPS-X simulation was used to predict how a WWTP behaves under different operating conditions and to suggest ideas for future improvement. GPS-X version 8.5 was applied for dynamic modelling and simulation to check the performance of the Arab Abo Saed Wastewater Treatment Plant in Helwan, Egypt. Two operating cases were studied: one with the highest water flow and the lowest pollutant levels, and another with the lowest water flow and the highest pollutant levels. Real data from two years (2022–2023) was used for calibration and validation. Sensitivity analysis was done to adjust some stoichiometric and kinetic values so that biological processes were shown correctly. The results of the simulated models were very closely matching the real existing situation in the plant, reaching 90% efficiency across all the stages of the treatment units. Regarding this approach, the GPS-X can be used efficiently to verify the WWTP design, analyse, and simulate the treatment plant behaviour under many conditions, and can help in the studies for future expansions. In addition, the modelling simulation results were very close to the existing operational performance for the plant, and also the modelling simulation was stating and identifying the options that shall improve the treatment plant performance regarding its effluent water quality and shall direct during the decision-making regarding the sustainable wastewater treatment management.*

Keywords *- Wastewater treatment, GPS-X simulation, Activated Sludge Model, Dynamic modeling, WWTP design, Model calibration.*

1. Introduction

The Nile River represents Egypt's primary source of freshwater, yet it faces increasing challenges due to rapid urbanization, population growth, uneven geographical distribution, and climate variability [1, 2]. In response, the Egyptian government has developed the Integrated Water Resources Management Strategy (IWRMS), which focuses on improving water-use efficiency, strengthening pollution control measures, particularly from wastewater discharges, and expanding investments in wastewater treatment, water reuse, and other non-conventional water resources [2].

These initiatives aim to safeguard public health, enhance resource sustainability, and mitigate the impacts of limited freshwater availability [2]. The country's limited water resources and how to improve the wastewater treatment and the reuse of treated wastewater. More than 200 wastewater treatment plants (WWTPS) have been established across the country, with a total treatment capacity of approximately 11 million m³ per day, serving nearly 18 million people [2]. Over the past decade, Egypt has made significant progress in implementing large-scale water infrastructure projects, especially in the fields of wastewater treatment and desalination [3].

The objective of these efforts is to maximize the utilization of available water resources, whether derived from wastewater or brackish water [4]. This commitment is reflected in the substantial number of new projects and tenders launched nationwide [5].

A particular focus has been directed toward wastewater treatment plants, which have notably increased in number and capacity. Moreover, many facilities originally constructed during the 1980s and 1990s are currently undergoing rehabilitation to restore their operational efficiency and reintegrate them into Egypt's modern wastewater management framework, aligning with the country's long-term vision for sustainable water resource development [1].

In the past, the design and evaluation of these facilities relied mainly on theoretical calculations and empirical design standards [3, 4]. However, with the advancement of digital tools, there has been a growing shift toward the use of modeling and simulation techniques [5, 6].

The modern technologies usually afford a more detailed understanding of each type of system behaviour, stating the advantages and limitations in the wastewater treatment processes, and an overall utmost plant performance [7, 8].

In this study, the methodology that had been used accommodates the advanced techniques of using modelling and simulation to ease the comparison between the actual results coming from the treatment plant, and its simulation within a controlled digitized environment [5, 9, 10]. With this approach, problems and weak spots in the system can be found, and simple plans can be made using the data to make the system work better and stay stable for a long time [8, 10].

The modelling simulations and analyses in this study were conducted using the GPS-X™ software, version 8.5. This program is strong and easy to use, and it helps create models of the biological, chemical, and physical steps in wastewater treatment processes [9, 11, 12].

In GPS X, the software is widely known, but its use at the Arab Abo Saed Wastewater Treatment Plant (WWTP) is seen as especially important because it shows how a large plant can still run well during Egypt's dry weather. In GPS X, the plant is located in Helwan and was once counted among Cairo's three largest treatment plants. In GPS X, the plant has a daily capacity of 550,000 m³/day and services many nearby communities [1]. Wastewater is cleaned in two main steps, primary and secondary treatment, both using the Conventional Activated Sludge (CAS) process [1].

In this study, the CAS system was placed under two extreme conditions, one with very high water flow and another with very high organic load. These tests were done to check if the design can stay safe and reliable in a developing setting. At the same time, the work shows how the plant plays a vital role in protecting health and the environment by removing organic matter and pollutants [1].

One of the main objectives of this study is to develop and propose some recommendations based on real data for a projection plan for the future capacity of the treatment plant, and how to raise and improve the treatment process in Arab Abo Saed WWP. Other objectives of this study are:

- Drawing a full simulation model for Arab Abo Saed WWTP using the GPS-X™ software and calibrating it with the real data.
- Inserting all the important process parameters, kinetic and stoichiometric, before the simulation process to ensure the most accurate results, and outcome of the physical and biological processes in the plant.
- Comparing the treatment plant's performance under two scenarios:
    - Maximum influent flow with average pollutant concentrations.
    - Average influent flow with maximum pollutant concentrations.
- Comparing the results from both scenarios with the Real data
- Validating the current simulated model and providing a clear database idea to help in future planning, whether to increase the plant capacity, improve the processes, or make the plant work better overall.

2. Materials and Methods

The Arab Abo Saed WWTP model was made with GPS-X™ version 8.5 simulation software. The Mantis2 biological library was used inside GPS-X v8.5 to shape and adjust the system. By this setup, the plant's processes were shown in a clear way, and the behavior of the treatment system under different conditions was studied. This model intends to show the real circumstances at the Arab Abo Saed Wastewater Treatment Plant (WWTP), located in Helwan, Egypt [1].

This facility mainly employs the standard activated sludge method for its secondary cleaning phase, and its cleaned outflow is released into the Al-Saff Irrigation Canal. In order to assess the accuracy of the model and verify the simulation output and to determine the actual plant performance, simulation results are compared with real operational data collected from the plant. This comparison aims to provide model calibration. The work plan for the case simulation is illustrated in Figure 1.

2.1. Design Methodology

Various site visits were conducted at the Arab Abo Saed WWTP to observe and thoroughly understand the operational processes and issues within the facility. Different operational data were collected from the WWTP operators, with a particular focus on comprehensive consecutive records for two entire years.

Additionally, representative samples were obtained for detailed laboratory analysis and quality control. Figure 2 presents the layout of Arab Abo Saed WWTP, which operates at a treatment capacity of 550,000 m³/day.

2.2. Process Design Description

Table 1 and Table provide a holistic view of the plant's infrastructure and the quality of the influent wastewater to understand the plant's capacity and treatment performance. The number of tanks used in each treatment stage, along with their corresponding dimensions and designed capacities at Arab Abo Saed WWTP, are illustrated in Table.

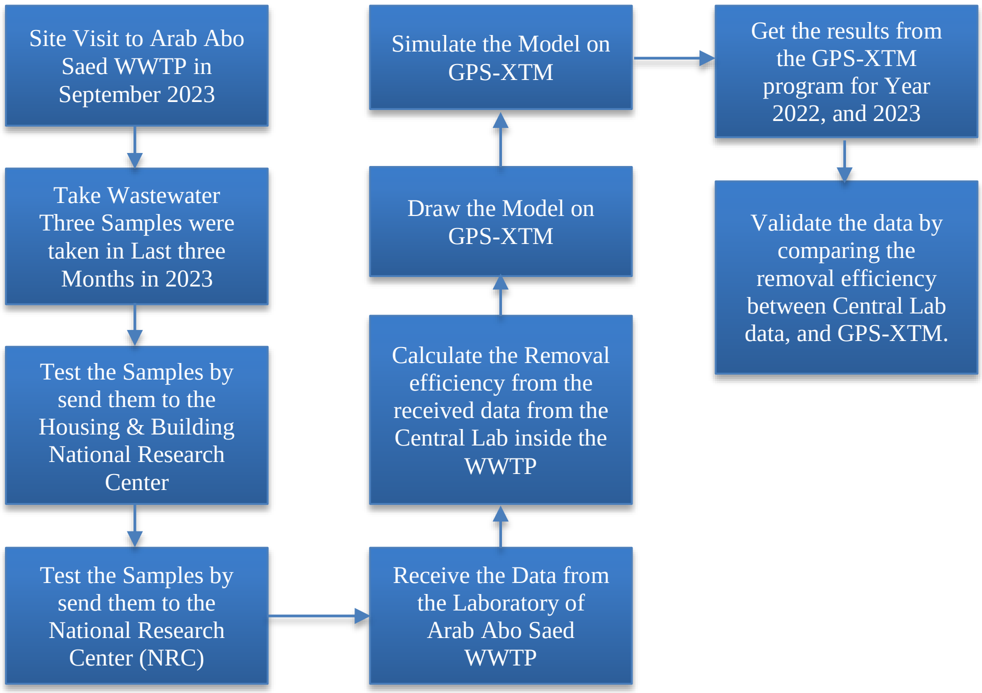


Fig. 1 Workplan for the simulation cases

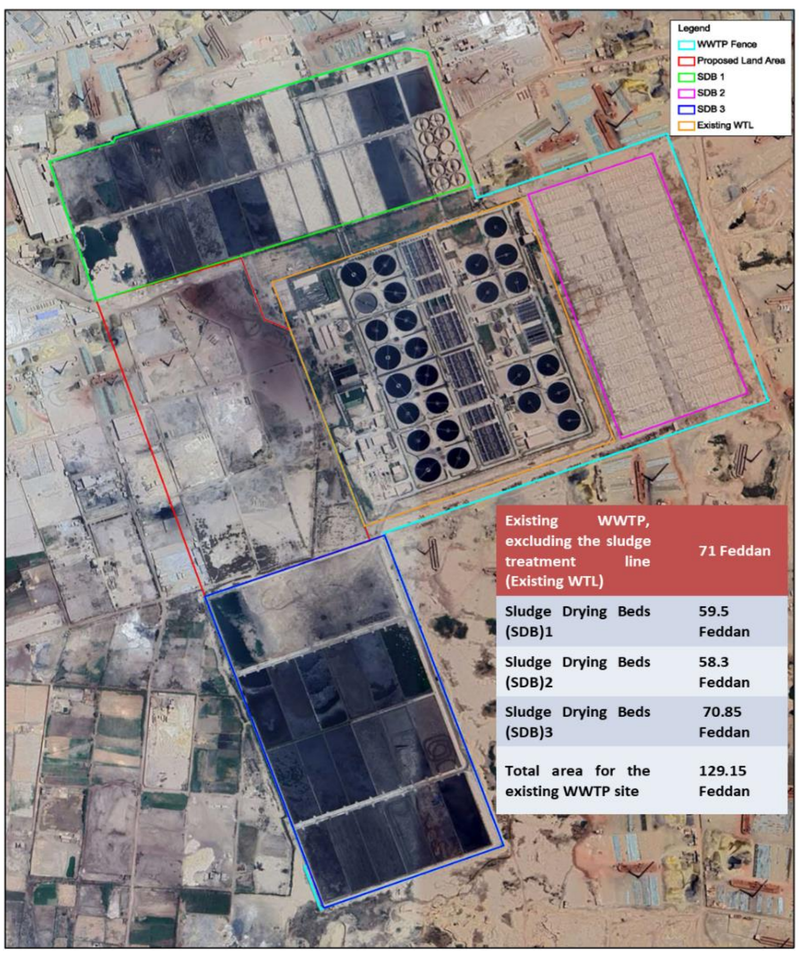


Fig. 2 Arab Abo Saed WWTP layout [1]

Table 1. Updated design parameters for Arab Abo Saed WWTP [1]

Parameter	Unit	Value
Daily Average Flow	m^3	550,000
Peak Factor		1.25
Max Process Flow	(m^3/sec)	7.96
Max Hydraulic Flow Rate	(m^3/sec)	8.5
TSS (max. value)	mg/l	800
TSS (avg.)	mg/l	500
BOD5 (max. value)	mg/l	370
BOD5 (avg.)	mg/l	290
Intermittent Peak BOD5	mg/l	450
COD (max. value)	mg/l	800

Table 2. Capacities and dimensions of existing treatment tanks

Tanks	No of Tanks	Diameter (m)	Depth (m)	Volume for Each Existing Tank (m^3)
Primary Sedimentation Tanks	10	46	3	5,000
Aeration Tanks	4	33.20*52	1.7	2,900
Aeration Tanks	8	35.40*50.50	2.2	3,780
Final Sedimentation Tanks	12	46	3.16	5,249
Final Sedimentation Tanks	4	52	4.25	9,021

Table 1 shows the main characteristics of the wastewater entering the wastewater treatment plant, which includes physical, chemical, and biological properties. These characteristics show a detailed quality of the influent water. There are major parameters, such as BOD, COD, TSS, pH, Temperature, ammonia, and other important components, which are included to show and present the raw sewage composite samples.

While the study focuses on evaluating the performance of the Arab Abo Saed WWTP, the results generated by the simulation software were compared with the plant's actual operating conditions. The current operational conditions of the plant and two design scenarios were analyzed: Two design scenarios were analyzed:

Scenario 1: Maximum flow with average influent concentrations.

Scenario 2: Average flow with maximum influent concentrations.

The process flow diagram developed in this study includes the following units: the pre-treatment stage, comprising the Screen Chamber and Grit Removal Unit; the primary treatment stage, comprising the Primary Clarifier; and the secondary treatment stage, comprising the Aeration Tank and Final Sedimentation Tank.

Arab Abo Saed WWTP's design followed the international standards and guidelines. The design of the tanks was based on composite samples of the influent wastewater and takes into consideration safety factors, as well as the required effluent treated water characteristics, following the guidelines stated in the Egyptian Code of Practice (ECP) and Law No. 48/1982. Law 48/1982 was innovated and published to raise awareness in society and protect the water bodies in Egypt, such as the Nile River, from any pollution.

The results of this design, like tank sizes, loading rates, and how well the treatment works, are stated in the next section. These results give a clear base to check how the plant works now and how it might work in the future.

2.3. Design of Wastewater Treatment Plants (CAS)

The Arab Abo Saed WWTP was designed to operate with the Conventional Activated Sludge (CAS) process, which includes preliminary, primary, and secondary treatment. In this study, sludge treatment was not considered because the required data were unavailable.

This omission was taken as an assumption, but its impact was reduced by adjusting the influent fractions so that the missing return liquor loads were reflected. In this way, the overall system was still represented in a reliable and consistent manner.

2.4. Verification of the Operational Conditions using Mathematical Modelling

The model simulation was conducted using GPS-X™ (v.8.5) software (Hydromantis Inc., Ontario, Canada) to verify and optimize the plant design under the two proposed scenarios. The Arab Abo Saed treatment system was studied during normal operation and also during sudden changes, such as higher organic loads and increased incoming flow. The expected effluent quality was then compared with the required standards to see if the design was suitable, too large, or too small. The same design rules were used in both the design and evaluation stages so that the comparison would be clear and reliable.

In this study, two proposed scenarios were drawn in the shape of models to be simulated by using GPS-X™ modelling software. The first scenario considered at the plant's performance is the maximum hydraulic loading with average influent concentrations, while the second focused on average hydraulic loading with maximum influent contaminant concentrations. Both scenarios were over two years (2022-2023) to fully understand how the plant works under different conditions. The results from these simulations will be discussed in the next section. In the following text, Scenario 1 refers to maximum hydraulic loading with average influent concentrations, and Scenario 2 refers to average hydraulic loading with maximum influent contaminant concentrations.

In the purpose of validating the simulated models, the Root Mean Square Error (RMSE) statistical method is one of the methods that can be used to validate, certify, and assure the simulated model with its output concentrations regarding the existing measured concentrations of the effluent, whether TSS, BOD, and COD. The equation of the RMSE is

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - M_i)^2}$$

where S_i and M_i describe the simulated and the measured values consecutively, and n is the number of interpretations. When the value of the RMSE is low, this confirms and validates the model's capability to generate very close results regarding the actual data regarding the wastewater treatment plant process regarding the TSS, COD, and BOD. In addition, the performance of the wastewater treatment plant is evaluated in terms of reducing the pollutants instead of the absolute concentrations, and because of that, the most appropriate method for model validation is the Removal Efficiency.

The removal efficiency presents the treatment process effectiveness by comparing the influent and the effluent concentrations, which makes it clearer to observe and evaluate the treatment plant performance under different flow and loading conditions. Consequently, the combination of using RMSE for the accuracy of the statistical results and the removal efficiency for the evaluation of the treatment plant process shall provide a clear and reliable validation for the developed model.

3. Results and Discussion

The Results and Discussion section is divided into two parts. For the initial section, the framework obtained actual facility measurements. The testing outcomes were checked against the readings from GPS-X (version 8.5), and necessary changes to important figures were performed until a very similar outcome appeared. The model became more accurate, and it gave a clear and reliable view of how the plant works. This clear view helps the team plan the next steps and guide future improvements.

The model was checked using new data collected later. Data from the first year were used to set up the model, while data from the second year were used to test how well it could predict results. The model outputs were then compared with the plant's real measurements to confirm that the results were accurate and consistent.

After this step, the model was evaluated as strong enough to estimate future performance and to support design updates and operating changes. This step also showed which parts of the model still needed improvement. In general, GPS-X proved to be a reliable tool for studying and improving wastewater treatment plants.

3.1. Calibration for Year 1

3.1.1. Field Investigations and Data Collection

Several site visits were carried out at the Arab Abo Saed Wastewater Treatment Plant. During each visit, samples were taken from the main treatment units while the plant was operating under normal, steady conditions. This approach was used to understand the plant's real performance. All samples were analysed in the plant's central laboratory using standard methods.

The laboratory work focused on basic water quality tests that are widely used in wastewater studies. These tests included Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and pH. Together, these indicators give a clear picture of how well each treatment step removes pollution.

Sampling locations were chosen to represent the main stages of treatment. Wastewater was collected after the grit removal chamber using an autosampler. Additional samples were taken from the outlets of the primary settling tanks, the final settling tanks, and the chlorination unit. This made it possible to follow how water quality changed as the wastewater moved through the plant.

In each monitoring round, four samples were collected and sent to the central lab for testing. Sampling was repeated throughout the year to capture changes related to seasons, weather, and flow conditions. The same sampling and testing procedure was followed every time to keep the results consistent and comparable. Plant flow was recorded continuously. From these records, the annual average, peak, and minimum flows were calculated. These values were then used to understand how changes in flow affected the treatment performance.

Samples were collected at several points in the plant to see how well pollutants were removed and how well the system was working. At the inlet, the raw wastewater was tested to set the starting values. After the primary tanks, lower solids and lower organic load were recorded because settling took place there. After the final tanks, the results of biological treatment were checked, and the water clarity was reviewed.

At the chlorination unit, final samples were taken to confirm that the treated water met the discharge limits. In order to give a clear view of how each stage worked, the Table 2 results were later used as input for model testing. Lab results and flow checks were used to set up two study cases that showed how the plant worked under different loads. In the first case, the highest flow rate with average pollution levels was used. In the second case, the average flow rate with the highest pollution levels was used. These two cases were used to check if good treatment could still be maintained during high flow and during high pollution. A short summary of the results, including inlet and outlet values and the removal rate for each treatment stage, is shown in Table 3 below.

Table 2. Comparative summary of scenario (1) and scenario (2) conditions throughout the WWTP

Parameter	Unit	Inlet Chamber		Primary Sedimentation		Final Sedimentation		Chlorination Tank	
		mg/L	RE (%)	mg/L	RE (%)	mg/L	RE (%)	mg/L	RE (%)
Scenario 1: Maximum Influent Flow = 649,644 m³/day									
TSS	mg/L	322	100	118	63.35	24	92.44	25	92.24
BOD	mg/L	287	100	123	57.14	25	91.28	27	90.59
COD	mg/L	476	100	185	61.13	45	90.55	47	90.13
Scenario 2: Average Influent Flow = 570,609 m³/day									
TSS	mg/L	540	100	441	18.33	37	93.15	40	92.59
BOD	mg/L	410	100	256	37.56	34	91.71	38	90.73
COD	mg/L	680	100	285	58.09	58	91.47	68	90

3.1.2 Model Development and Simulation

A model of the Arab Abo Saed Wastewater Treatment Plant was made using GPS X version 8.5. A dynamic model was first set up so the plant could be followed over time under certain running conditions.

All the needed input data were then added to the program. This included tank sizes, the quality of the incoming wastewater, flow rates, and other basic values needed to make the model close to the real plant. The model was then calibrated using lab results. Key reaction and process values were adjusted until the model results were close to the real plant results.

The flow diagram of the WWTP as configured in GPS-X is shown in Figure 3.

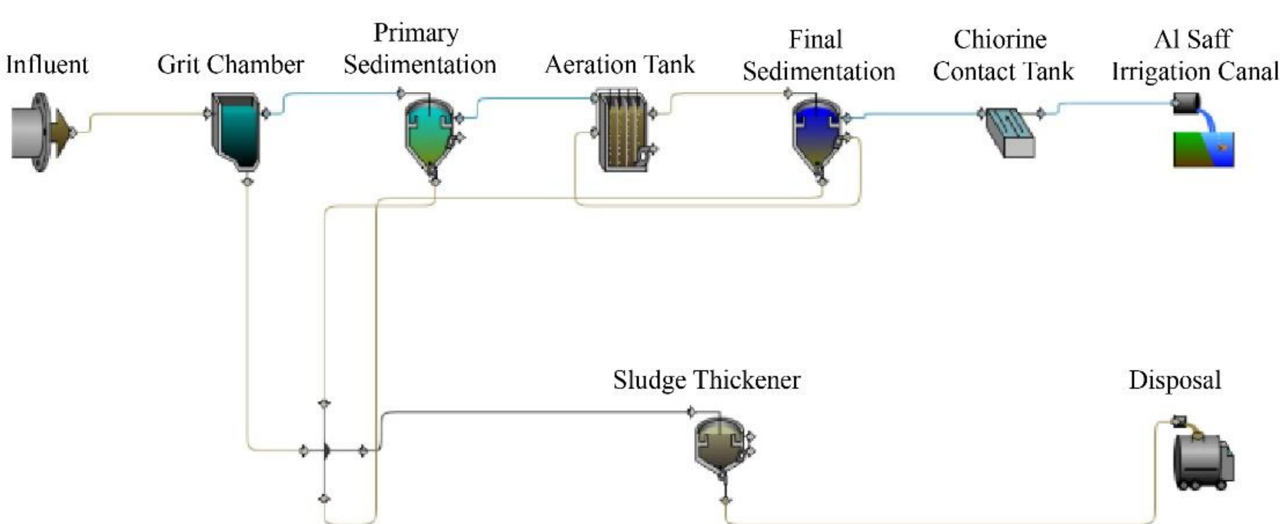


Fig. 3 Layout for the Arab Abo Saed WWTP in the GPS-X program

As shown in Figure 3, the model was built and calibrated, and a comparison was carried out between the measured operating data and the simulated results. This comparison was needed to check the accuracy of the model and to confirm that the real performance and behaviour of the treatment plant were correctly represented. A clear view of plant efficiency was obtained by using lab results together with the calibrated simulation results. This work was used as a base for later optimization and design improvement.

3.1.3. Model Calibration and Parameter Selection

Calibration of the Conventional Activated Sludge model was carried out in a planned, step-by-step way. First, the wastewater treatment plant layout was built in GPS-X, and the required operating data were entered. Then, a first simulation was run using the default biology settings. In this run, the model predicted the water quality and the level of biomass activity.

In GPS-X, almost 60 built-in parameters are used to describe the treatment steps, including the biological steps. In this work, a full review of all parameters was not seen as practical or needed [2]. In this work, only a small set of key parameters was chosen, because these parameters strongly affect plant performance and operation, and they can change how well the model fits real data. In this work, this approach was also used in earlier studies based on the ASM1 activated sludge model, where the most important parameters are given priority during calibration.

Sensitivity analysis was used to help choose the right parameters. This method found which parameters had the biggest effect on how the system worked and left out those that had a negligible effect. Doing this made the process faster and made the calibration stronger and more reliable.

Table 4. Parameters and kinetic values used for calibration

Parameters	Modified GPS-X Values	Default GPS-X Values
Influent Composition		
Total COD	476 gCOD/m3	430 gCOD/m3
Influent Fractions		
VSS/TSS Ratio	0.10 gVSS/gTSS	0.75 gVSS/gTSS
Organic Fractions		
Colloidal Fraction of Slowly Biodegradable COD	0.9	0.15
pH and Alkalinity		
pH	7.8	7

The study provided a systematic calibration with a solid foundation for subsequent validation, which ensures that the simulated outputs are very reliable and close to the actual performance of Arab Abo Saed WWTP.

3.1.4. Simulation and Performance Evaluation

The Arab Abo Saed WWTP was drawn, modelled, and then simulated to evaluate the performance of the plant under two scenarios, which were mentioned previously in the Materials and Methods section. These simulations were made to focus on and measure the plant response under different organic and hydraulic loading conditions, then validate the model regarding the actual field data.

The two scenarios that were mentioned previously were simulated for Year 1, in the same period that the samples were tested in the laboratory, and flow monitoring. Also, at this period, the results of the simulations were able to be compared directly with the treatment plant performance, which helped in improving the validity of the model calibration and the subsequent analysis. The efficiency of removal, which is considered a key factor to calculate the water quality parameters, is calculated as follows:

$$\text{Removal Efficiency (\%)} = \frac{(\text{Influent} - \text{Effluent})}{\text{Influent}} \times 100$$

In addition, the influent and effluent present the concentrations of each parameter at the inlet and outlet of the treatment system separately.

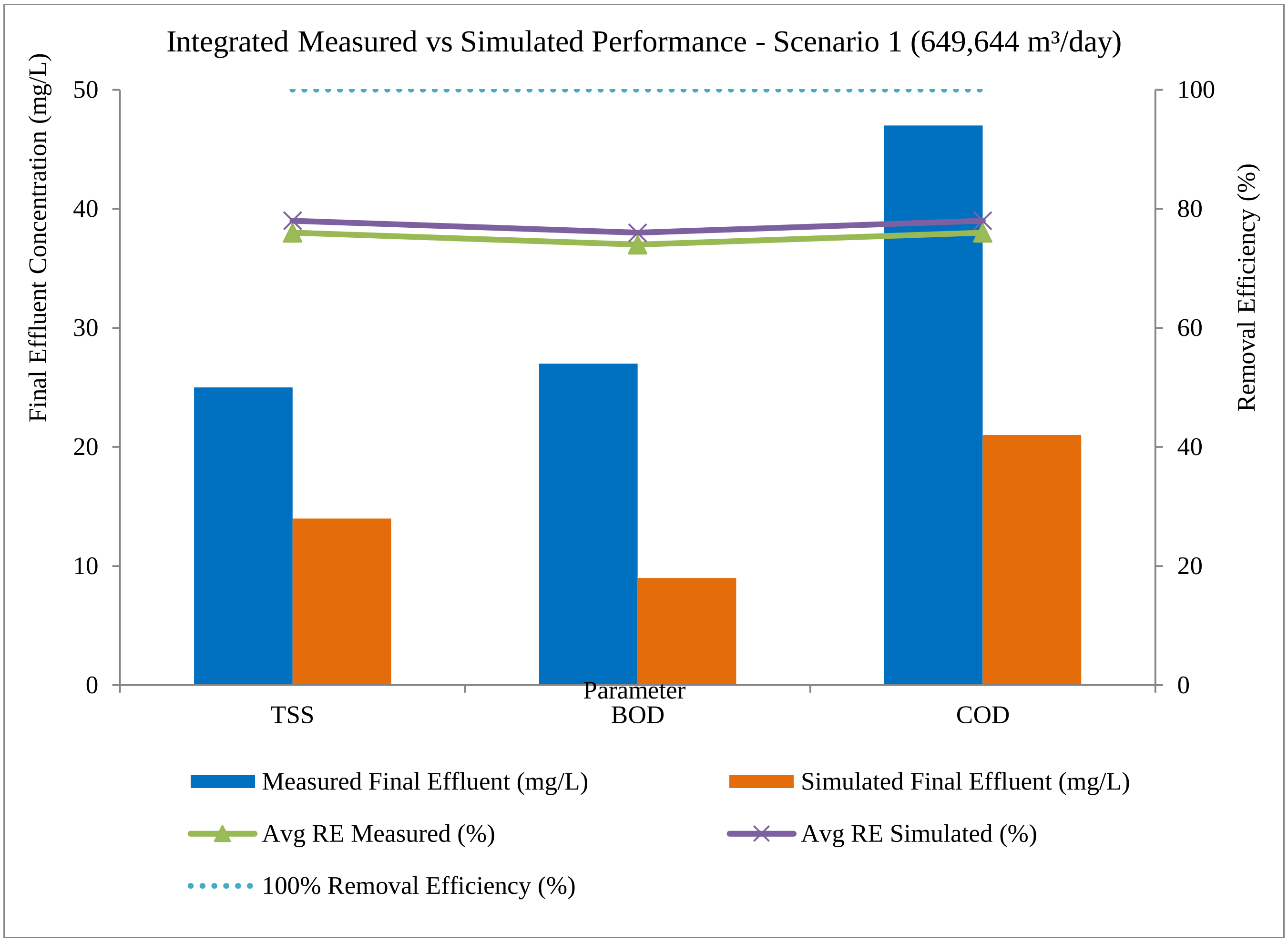
The results of the simulation model that was conducted by GPS-X are represented in the following figures. These results presented the hydraulic and biological performance for the process of the treatment system under the chosen scenarios, focusing on the efficiency of treatment units separately, and all of them together in the treatment plant.

The results that were received present that there is a stability in the operation, and also the plant is capable of sustaining the treatment operation to provide the required effluent quality under several changes that occur in the operation time.

The following figures present a detailed projection regarding the simulation results.

Table 3. Arab Abo Saed WWTP year 1: water quality and removal efficiencies – GPS-X™ simulation including RMSE

Scenario 1: Maximum Influent Flow = 649,644 m³/day									
Parameter	**Influent**	**Primary Sedimentation**		**Final Sedimentation**		**Chlorination Tank**		**MSE**	**RMSE (mg/L)**
		Measured (RE %)	**Simulated (RE %)**	**Measured (RE %)**	**Simulated (RE %)**	**Measured (RE %)**	**Simulated (RE %)**		
TSS	322	118 (63.35%)	120.66 (63%)	24 (92.44%)	24.60 (92%)	25 (92.24%)	13.68 (96%)	45.19	6.72
BOD	287	123 (57.14%)	120.84 (58%)	25 (91.28%)	24.49 (91%)	27 (90.59%)	9.49 (97%)	103.84	10.19
COD	476	185 (61.13%)	155.85 (67%)	45 (90.55%)	41.79 (91%)	47 (90.13%)	21.54 (95%)	502.75	22.42
Scenario 2: Average Influent Flow = 570,609 m³/day									
Parameter	**Influent**	**Primary Sedimentation**		**Final Sedimentation**		**Chlorination Tank**		**MSE**	**RMSE (mg/L)**
		Measured (RE %)	**Simulated (RE %)**	**Measured (RE %)**	**Simulated (RE %)**	**Measured (RE %)**	**Simulated (RE %)**		
TSS	540	441 (18.33%)	87.07 (84%)	37 (93.15%)	55.98 (90%)	40 (92.59%)	10.48 (98%)	42166	205.3
BOD	410	256 (37.56%)	163.05 (60%)	34 (91.71%)	50.32 (88%)	38 (90.73 %)	14.81 (96%)	3147.94	56.11
COD	680	285 (58.09%)	229.28 (66%)	58 (91.47%)	63.56 (91%)	68 (90 %)	18.05 (97%)	1876.88	43.32



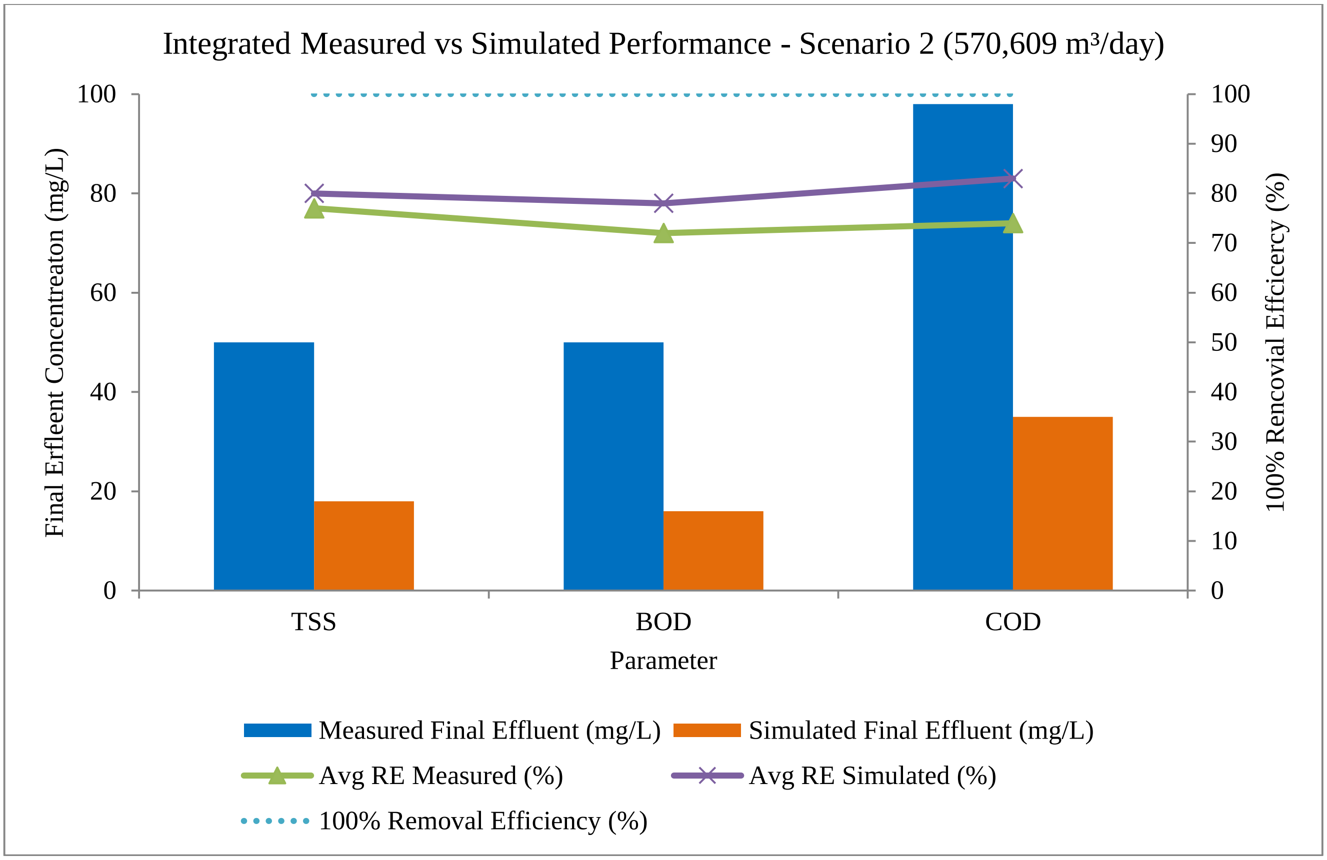


Fig. 4 GPS-X™ modelled pollutant concentrations by process unit for phases (1) and (2)

3.2. Validation for Year 2

Based on Table 3, the model is validated using the Root Mean Square Error (RMSE) statistical method. In this section, there will be an integration of the detailed data for Year 2 received from the laboratory analyses, which were obtained from the site, which will help in improving and developing the previous model while using GPS-X that had been calibrated before, and projecting to enhance the validity, and making it more compatible. In addition, there will be a comprehensive comparison between the results received from the simulation and the current performance results that were received from the treatment plant to ensure and verify the model's accuracy and representativeness. This method was used to keep the model's structure and settings the same, so a clear and steady base was made for comparing how the system worked in different years.

The following modelling steps are the same steps that were followed in the original model, and keep the same limitations, coefficients, and assumptions that were defined and inserted in the previous model. The model has been simulated for two different scenarios, which were stated, described, and presented in great detail in the previous chapter. After the simulation had been completed, a very detailed analysis of the results was provided to analyze the treatment plant performance regarding the influent and effluent quality parameters. A summary of the influent wastewater characteristics and the other kinetic parameters, which were used as initial variables in the model, will be presented in the following Table.

Table 6. Arab Abo Saed WWTP influent WW characteristics for year 2

Parameter	Unit	Inlet Chamber
Scenario 1: Maximum Influent Flow = 649,644 m³/day		
TSS	mg/l	417
BOD	mg/l	328
COD	mg/l	600
Scenario 2: Average Influent Flow = 570,609 m³/day		
TSS	mg/l	542
BOD	mg/l	398
COD	mg/l	694

After the data from the influent were included in the GPS-XTM model, the simulation was executed to forecast the performance of the treatment plant under the circumstances that were chosen for operation.

Table 4. Results from GPS-XTM for year 2

Scenario 1: Maximum Influent Flow = 699,644 m³/day									
Parameter	**Influent (mg/L)**	**Primary Sedimentation**		**Final Sedimentation**		**Chlorination Tank**		**MSE**	**RMSE (mg/L)**
		Measured (RE %)	**Simulated (RE %)**	**Measured (RE %)**	**Simulated (RE %)**	**Measured (RE %)**	**Simulated (RE %)**		
TSS	417	113 (73 %)	129.24 (76 %)	20 (95 %)	42.87 (92 %)	19 (95 %)	12.65 (98 %)	275.699	16.6
BOD	328	122(63 %)	171.12 (57 %)	24 (93 %)	55.4 (86 %)	23 (95 %)	20.18 (95 %)	1135.56	33.7
COD	600	165 (73 %)	242.93 (65 %)	44 (93 %)	77.28 (89 %)	43 (95 %)	47.29 (93 %)	2399.68	48.99
Scenario 2: Average Influent Flow = 619,262 m³/day									
Parameter	**Influent (mg/L)**	**Primary Sedimentation**		**Final Sedimentation**		**Chlorination Tank**		**MSE**	**RMSE (mg/L)**
		Measured (RE %)	**Simulated (RE %)**	**Measured (RE %)**	**Simulated (RE %)**	**Measured (RE %)**	**Simulated (RE %)**		
TSS	542	240 (56 %)	111.75 (79 %)	30 (94 %)	31.41 (94 %)	32 (94 %)	9.82 (98 %)	5647.33	75.15
BOD	398	175 (56 %)	174.69 (57 %)	33 (92 %)	73.83 (82 %)	32 (92 %)	12.67 (97 %)	680.278	26.08
COD	694	185 (73 %)	238.99 (65 %)	57 (92 %)	89.08 (87 %)	57 (92 %)	23.86 (96 %)	1680.77	41

Table 7 displays the outcomes of the two different scenarios used in the operation. It is possible to evaluate the overall effectiveness of the treatment system with the assistance of the table, which provides a listing of the predicted effluent quality as well as the removal efficiency at each particular treatment step.

After the GPS-X™ simulation results were received, they were compared with the lab data collected from the Wastewater Treatment Plant (WWTP). This comparison was done to see how close the simulated results were to the real ones. It was used as a step to check if the model was accurate, reliable, and able to show how the plant really worked.

Subsequently, the results that were taken from the models after the simulations for the two scenarios that were proposed previously, and the results of the central labs of the treatment plant, were used to establish a unified comparison. The comparison showed that the results of the simulation models and the existing data are very close, with a small difference, which confirms the model's reliability and predicts the results and the output water quality.

Furthermore, the steps of model calibration were described previously, and the model has been considered, and it has been assured that the model is able to predict the future results on the wastewater treatment plant regarding all conditions. It was stated that the results of the simulated models were usually higher than the results of the existing situation, which is expected because the model is simulated under very ideal conditions, regardless of the human errors, any change in the operation technique, or any small errors that can occur in the operation.

The model reliability was measured using removal efficiency, and solid arrangement was found for the effluent parameters with values of 94% for BOD, 92% for TSS, and 91% for COD, thus moving forward with the percentage accuracy. These values were higher than those reported in recent GPS-X studies on similar CAS plants in the MENA region, which often show accuracies near 85% [2], further confirming the strength and reliability of the model.

4. Conclusion

This study focuses on generating two design configurations for Wastewater Treatment Plants (WWTPs) and then follows with configuration verification by dynamic modeling using GPS-X version 8.5. The results of the conceptual design methodology show that it is feasible to achieve efficient treatment performance and generate high-quality efficiency when paired with appropriate construction techniques and operating methods. This facilitates the selection of optimum treatment techniques adapted to site-specific circumstances.

The usage of GPS-X has proven to be an effective tool for testing preliminary WWTP designs. This provides a full evaluation of the treatment plant's performance under different scenarios regarding hydraulic and organic loading, and it can also provide a future projection for the needed requirements for improving the performance, and to sustain that in future development.

The current study was limited by the absence of continuous nutrient data for nitrogen and phosphorus, as well as by the assumption of steady state behavior during peak flow simulations. Despite these limits, it remained important that such boundaries and guidelines were considered since the design of a treatment plant is a complex and evolving technical task. The principles of the design were integrated with the current future modelling and simulation techniques, and the output results were presented in a very detailed way. This combination was very important to notice and state the key features that can impact the treatment plant performance and can help in improving the plant output results. This will impact the decisions regarding any future prospects regarding the plant and get an accurate result, thus supporting the plant design of the wastewater treatment plant. The results of the modelling and simulation models have shown that they are relatively close to 90% of the actual treatment plant results across all the treatment stages, which assures that there is mutual matching between the practical and theoretical values. Although some limits were present, this level of agreement proved that the model could serve as a digital twin of the Arab Abo Saed facility. Through this framework, a useful guide was provided for practitioners in Egypt to improve the performance of existing plants and to support decisions that encourage sustainable wastewater management. This approves that the drawn model is a mirror of the existing treatment plant on site, which may work as the real existing plant to apply some modifications to improve it till it approaches the required effluent of the treated wastewater. Additionally, the results provided from the modelling and simulation were better than those of the real existing treatment plant, which relies partially on minimizing human errors during the operation time. This ensures that the GPS-X program is not only a modelling and simulation program or a tool that should raise the treatment process in virtual models, but also can improve the real existing situations in the treatment plants. The GPS-X application is a revolutionary methodological framework that promotes WWTP efficiency and provides a reference for future research and practitioners in the region, demonstrating the program's efficiency across numerous important elements.

Data availability

Enquiries about data availability should be directed to the authors.

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Declaration of Competing Interest

The authors declare that they have no known personal relationships or competing financial interests that could have influenced the work stated in this paper. ≈M.S. & M.M. contributed equally.

Credit Authorship Contribution Statement

Salaheldin, M.: Conceptualization, Methodology, Data curation, Writing - original draft, Investigation, and Visualization. Meshref, M.: Conceptualization, Data curation, Methodology, Supervision, Writing - original draft, Writing - review & editing, Visualization, and Validation. Ibrahim, M. Conceptualization, Writing - review & editing, Methodology, Resources, Supervision, and Validation. Hegazy, M.: Conceptualization, Resources, Methodology, Writing - review & editing, Data curation, Visualization, Supervision, Validation.

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