Avrupa Bilim ve Teknoloji Dergisi
Özel Sayı 47, S. 37-41, Ocak 2023
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Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
Special Issue 47, pp. 37-41, January 2023
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Research Article

Quantitative study for the effect of water velocity on water quality change

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(3rd International Conference on Engineering and Applied Natural Sciences ICEANS 2023, January 14 - 17, 2023)

(**DOI:** 10.31590/ejosat.1231931)

ATIF/REFERENCE: Assar, W. (2023). Quantitative study for the effect of water velocity on water quality change. *European Journal of Science and Technology*, (47), 37-41.

Abstract

Atmospheric reaeration process plays a key role in degradation of organic matter and self-purification processes affecting dissolved oxygen (DO) concentrations in rivers and streams. Moreover, water quality (WQ) processes can be highly dependent on flow velocity conditions. Where, highly reaeration rates are positively correlated with high flow velocity. Therefore, the present work reports deep insights on the role of flow velocity with reaeration process in the concentration of DO and biochemical oxygen demand (BOD_5). This study was applied along the largest agricultural drainage water reuse project, El-Salam Canal in Egypt. The hydrodynamic (HD) characteristics and WQ parameters (DO and BOD_5) along the canal were simulated using a one-dimensional HD and WQ model (MIKE 11). The simulated results indicated that the canal was deteriorated towards El-Salam Canal after mixing with El-Serw and Bahr Hadous drains. Statistical regression fitted line and Pearson correlation analysis, were performed on the simulation results of the reaeration rates with flow velocity and WQ values, indicating a significant correlation. Accordingly, water velocity should be taken into account as a key factor for describing the WQ change.

Keywords: El-Salam Canal, flow Velocity, MIKE 11, Water Quality.

Su hızının su kalitesi değişimi üzerindeki etkisine yönelik nicel çalışma

Öz

Atmosferik yeniden havalandırma süreci, nehirlerde ve akarsularda çözünmüş oksijen (DO) konsantrasyonlarını etkileyen organik maddenin bozunmasında ve kendi kendini saflaştırma süreçlerinde kilit bir rol oynar. Ayrıca, su kalitesi (WQ) süreçleri büyük ölçüde akış hızı koşullarına bağlı olabilir. Burada, yüksek yeniden havalandırma oranları, yüksek akış hızı ile pozitif olarak ilişkilidir. Bu nedenle, mevcut çalışma, DO konsantrasyonunda ve biyokimyasal oksijen ihtiyacında (BOD_5) yeniden havalandırma işlemi ile akış hızının rolü hakkında derin görüşler bildirmektedir. Bu çalışma, Mısır'daki en büyük tarımsal drenaj suyu yeniden kullanım projesi olan El-Salam Kanalı boyunca uygulandı. Kanal boyunca hidrodinamik (HD) özellikler ve WQ parametreleri (DO ve BOD_5), tek boyutlu bir HD ve WQ modeli (MIKE 11) kullanılarak simüle edilmiştir. Simüle edilen sonuçlar, kanalın El-Serw ve Bahr Hadous drenleri ile karıştırıldıktan sonra El-Salam Kanalı'na doğru bozulduğunu gösterdi. Yeniden havalandırma hızlarının simülasyon sonuçları üzerinde, akış hızı ve WQ değerleri ile istatistiksel regresyon uydurma çizgisi ve Pearson korelasyon analizi yapılmış ve önemli bir korelasyona işaret edilmiştir. Buna göre, su hızı, WQ değişimini açıklamak için kilit bir faktör olarak dikkate alınmalıdır.

Anahtar Kelimeler: El-Salam Kanalı, Akış Hızı, MIKE 11, Su Kalitesi.

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1. Introduction

Atmospheric reaeration process plays a key role in degradation of organic matter and self-purification processes affecting dissolved oxygen (DO) concentrations in rivers and streams[1]. Where, DO concentrations are an important index for quantifying the water quality (WQ) of water bodies. Moreover, the level of DO reflects the ecological balance in water, decomposition of organic matter and breathing of aquatic ecosystem [2].

Recent studies illustrated that the DO distribution in water bodies has been strongly affected by the flow field and its turbulence characteristics [3]. Moreover, WQ processes can be highly dependent on flow velocity conditions. Where, highly reaeration rates are positively correlated with high flow velocity [4]. Based on the role of flow velocity with reaeration process in the concentration of DO and biochemical oxygen demand (BOD_5) were investigated.

To date, WQ models are an ideal approach in the holistic evaluation and prediction of temporal and spatial water quantity and quality characteristics in aquatic ecosystems [5]. As, the Environmental Fluid Dynamics Code (EFDC), SOBEK software, Delft 3D, MIKE software and the Water Quality Analysis Simulation Program (WASP). Among them, the one-dimensional finite-difference model MIKE 11 is considered the most widely used hydrodynamic (HD) and WQ simulation software. The MIKE 11 has proved its computational stability, high accuracy and reliability, and accordingly it can be applied in large-scale designs of both simple and complex channel systems [6].

Therefore, the HD and WQ model (MIKE 11) was developed and applied along El-Salam Canal in Egypt. It is considered the largest agricultural drainage water (ADW) reuse project in Egypt, which is mainly used for reclamation of 620,000 hectares of the land located along the Mediterranean Sea of Egypt [5]. In 2013, El-Salam Canal is established for reuse with a capacity of approximately 0.872 Billion Cubic Meters (BCM)/year from the Nile water to be mixed with 1.235 BCM/year of water from Bahr Hadous drain, 0.980 BCM/year from El-Serw drain and 0.255 BCM/year from Faraskor drain [7].

Thus, the present study reports deep insights on the role of flow velocity with reaeration process in the concentration of DO and BOD_5 values which resulted from the MIKE 11 simulation.

2. Material and Method

2.1. Study Area

El-Salam Canal is a part of the North Sinai development project, which is the largest drainage water reuse project in Egypt that continuously receives a mixture of Nile River water and ADW. The canal is lied in the Eastern North region of the Nile Delta, with a total length of 88 km (Figure1a). The canal receives Nile fresh water from the Damietta tributary of which situated at upstream of Faraskor Dam. The ADW supply sites from Faraskor, El-Serw, and Bahr Hadous drains at distances of 1.80 km, 17.85 km, and 54 km from the intake, respectively (Figure 1b). This mixed water is mainly used to cultivate 220,000 hectares extending west of Suez Canal along the Mediterranean coast of Egypt [8]. By constructing Pump Stations 1 and 2 units, the flow rates along the main-stream of El-Salam Canal are controlled, to sustain a proper head for gravity flow (Figure 1b).

The monthly water discharges records along the canal were obtained from the Ministry of Water Resources and Irrigation (MWRI) for seven locations from the intake of the canal at 0.0 km, 1.80 km,17.85 km, 22 km, 53 km, 54 km and 88 km, from September 2012 to August 2014. Moreover, the average monthly WQ data were collected by the Drainage Research Institute (DRI) from September 2013 to August 2014 at five locations at 0.0 km, 1.80 km, 17.85 km, 54 km and 88 km along the canal.

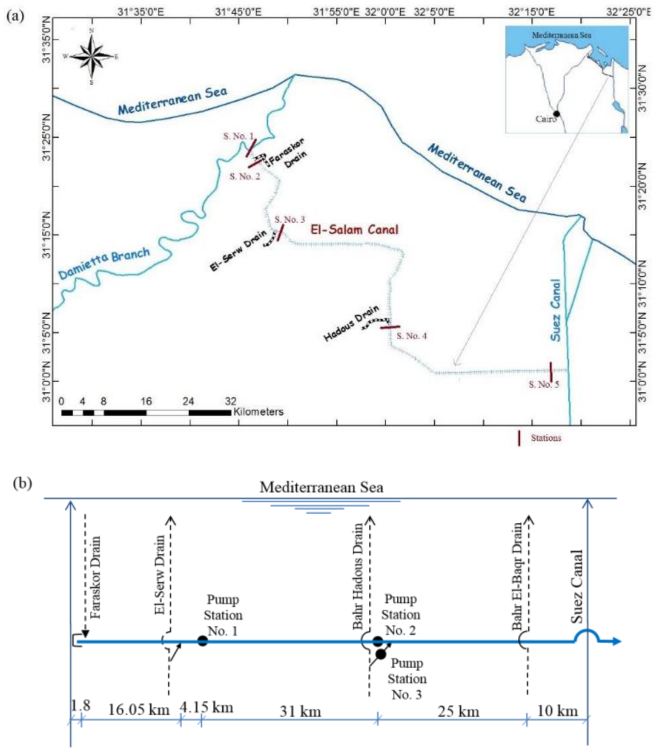


Fig. 1 (a) El-Salam Canal project layout, (b) schematic diagram of El-Salam Canal connected with Damietta Branch and agricultural drains

2.1.1. Water Quality Modeling

The 'MIKE 11' model was applied in this study to simulate the HD and WQ along El-Salam Canal. This model was originally developed by Danish Hydraulic Institute, for simulating hydrodynamics, advection-dispersion, WQ and sediment transport in rivers, lakes, estuaries and environmental hydraulics [9].

In the study, 88 km length of El-Salam Canal, with number of structures, specifically the head regulator of the canal intake, two siphons and two pump stations, was modelled. The MIKE 11 boundary editor was used to define the water levels and inflow hydrographs, where the initial upstream water level was set to 1.60 m. The simulation time step was set to five seconds to ensure the stability of the numerical calculations and keep the Courant number in the desired model's range [9].

The calibration process of the HD model was performed manually to adjust the Manning's roughness coefficient (n, sec/$m^{1/3}$) along El-Salam Canal, which considered the most critical factor in the HD simulation model [10]. The model was continuously run using HD data over one year from September 2012 to August 2013 to minimize the difference between the simulated and observed discharge records at two locations (Pump

Station 1 at 22.0 km and Pump Station 2 at 53.0 km), in the calibration phase.

For validation, the calibrated model was run using the data for a completely different year (from September 2013 to August 2014) to assess the ability to predict the water quantity and WQ under different conditions. The root mean square error (*RMSE*), mean absolute error (*MAE*) and normalized objective function (*NOF*) were applied to investigate the calibration and validation accuracy as follows: follows:

$$RMSE = \sqrt{\sum(Simulated\ value - Observed\ value)^2/N}$$

$$MAE = \sum_1^N |Simulated\ value - Observed\ value|/N$$

$$NOF = RMSE/O_{mean}$$

where:

N = the total number of values, and

O_{mean} = mean of the observed data.

Model simulations are acceptable for *NOF* values ranging from 0 to 1 [11].

3. Results and Discussion

The one-dimensional HD MIKE 11 model was developed to simulate the water quantity along El-Salam Canal. Firstly, the calibration process was performed from September 2012 to August 2013, enhancing the *n* value which achieved the lowest error was 1/40 sec/m$^{1/3}$. The results of performance statistics between the monthly observed and simulated discharges for Pump Stations 1 and 2 were 1.66 and 1.10 m^3/s of *RMSE*, 1.29 and 0.99 m^3/s of *MAE* and 0.02 of *NOF*, respectively. Secondly, from September 2013 to August 2014, the validation process displayed a good level of agreement between the simulated and observed discharges at Pump Stations 1 and 2. Where, the *RMSE*, *MAE* and *NOF* values were 2.94 m^3/s, 2.24 m^3/s and 0.04 for Pump Station 1, and 1.39 m^3/s, 1.06 m^3/s and 0.02 for Pump Station 2, respectively. The simulated results for the discharges of pump stations achieved from the model calibration and validation were consistent with the observed discharge values (with the low *NOF* values close to 0) evidenced the ability of the model to correctly simulate and investigate the impact of various processes along the canal. For the ECO Lab module (September 2013 to August 2014), the DO and BOD_5 values were calibrated at two different locations at: (1) 1.9 km after mixing with Faraskor drain (S. No. 2); and (2) 86 km before the downstream of the canal from the intake (S. No. 5), as shown in Figure 1a, (Table 1).

Overall, the model provided a reasonable agreement between the simulated and observed WQ data along El-Salam Canal.

The simulated DO and BOD_5 values were compared with the Egyptian standards for water reuse in irrigation purposes from September 2013 to August 2014 along El-Salam Canal at four selected stations from the intake and after mixing with the agricultural drains as shown in Figure 2. The four stations (S. No. 1, S. No. 2, S. No. 3 and S. No. 4) were located at 0.0 km, 1.85 km, 18.5 km and 55.0 km, from the intake, respectively, as shown in Figure 1a.

Table 1. The RMSE, MAE, and NOF for water quality parameters of El-Salam Canal

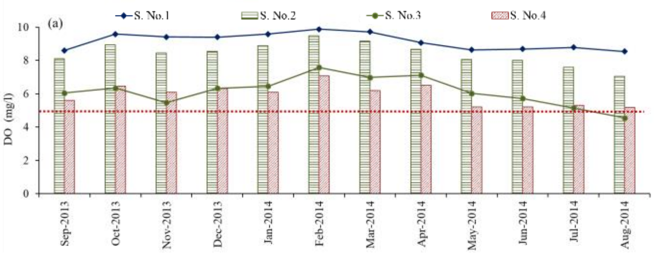
WQ Parameter	At 1.9 km			At 86 km		
	RMSE	*MAE*	*NOF*	*RMSE*	*MAE*	*NOF*
Temperature	0.02	0.01	0.001	0.09	0.09	0.004
DO	0.56	0.46	0.07	1.77	1.52	0.39
BOD_5	3.00	2.42	0.16	3.90	2.57	0.14

The simulated average monthly data for DO along El-Salam Canal varied from 4.5 mg/l to 9.88 mg/l, during September 2013 to August 2014, as presented in Figure 2a. The DO concentrations were within the Egyptian standards (DO > 5 mg/l) for direct reuse in irrigation along El-Salam Canal except at El-Serw drain (S. No. 3) in August. A significant decrease was observed in the DO levels after El-Serw (S. No. 3) and Bahr Hadous drains (S. No. 4), Figure 2a. For instance, the average DO concentration after the connection with El-Serw drain was 4.5 mg/l and 5.1 mg/l after the connection with Bahr Hadous drain in August. This was mainly due to the discharge of pollutants into these drainage canals resulting a depletion of oxygen concentration. [12], reported that the DO values decreased sharply towards the down-stream of El-Salam Canal after mixing with El-Serw and Bahr Hadous drains, which is consistent with the simulation results. Moreover, El-Gammal and Othman et al [8], [13] indicated that El-Serw and Bahr Hadous drains received a significant amount of untreated wastewater which subsequently adversely affected the DO concentration of El-Salam Canal.

As presented in Figure 2b, the simulated BOD_5 values along El-Salam Canal complied with the Egyptian standards (BOD_5 < 30 mg/l) for the direct water reuse for irrigation. However, the simulated BOD_5 concentration gradually increased from the intake point towards the down-stream after the connection with the drainage canals, as it exceeded the limit of 30 mg/l for reuse in May and June 2014, Figure 2b. The highest values of BOD_5 were 41.6 mg/l and 60.9 mg/l in May, and 34.3 mg/l and 44.7 mg/l in June at (S. No. 3) after mixing with El-Serw drain and at (S. No. 4) after mixing with Bahr Hadous drain, respectively. [14] reported that the supply of ADW to the canal caused high levels of BOD_5. Where, the BOD_5 values were 75 mg/l in June 2004 and 33 mg/l in November 2004 after mixing with El-Serw drain.

Therefore, the BOD_5 values of the canal were varied due to seasonal effects, as the high BOD_5 values were during summer season. It could be due to the discharge of wastewater rich inorganics into the drains, which negatively affected the WQ of the canal.

These results illustrated that the canal ecosystem deteriorated after mixing with water from El-Serw and Bahr Hadous drains due to the highly polluted untreated water discharged into the drains.



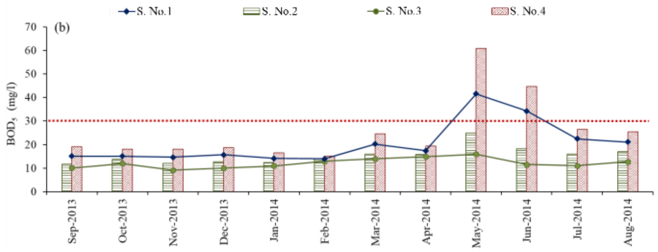


Fig. 2 Simulated (a) DO and (b) BOD_5 parameters at four stations (Stations No. 1– 4) for the period from September 2013 to August 2014.

Statistical analysis was performed on the simulation results for obtaining quantitative relationships using Minitab software with a significance level of $p < 0.05$. The inversely proportional between the DO and BOD_5 results was clearly showed from the simulated distribution along the canal, as Figure 3. Where, the high BOD_5 associated with the degradation of organic matters by heterotrophic bacteria occurred due to the decrease of DO [15]. These results were confirmed with the results of Pearson correlation analysis (r), which applied to evaluate the relationship between various variables. DO showed a significant strength negative relationship with BOD_5 ($r = -0.975$, $p < 0.05$), as Figure 4a, that obviously illustrated the fitted regression line between the DO and BOD_5 parameters.

Where, the DO deficit in the waterbody was proportional with the reaeration process, which, considered the difference between the saturated DO and the present DO concentration in the waterbody [16]. The higher rate of reaeration rates indicates the larger DO deficit. Moreover, the large reaeration process positively based on water flow capacity, which lead to strong turbulence and mixing activities in the waterbody, as presented in Figure 3. Therefore, the correlation between the flow velocity and reaeration rate was displayed, as shown in Figure 4b. The result of relationship between reaeration rates and flow velocity along the canal were demonstrated a significant positive correlation ($r = 0.910$, $p < 0.05$).

Accordingly, water flow velocity is considered a key role for describing the WQ change along the canal, which should be taken into account in investigating various WQ processes in waterbodies.

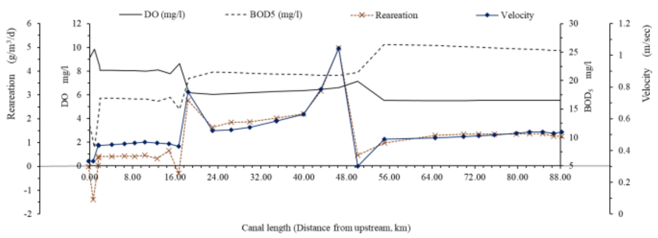
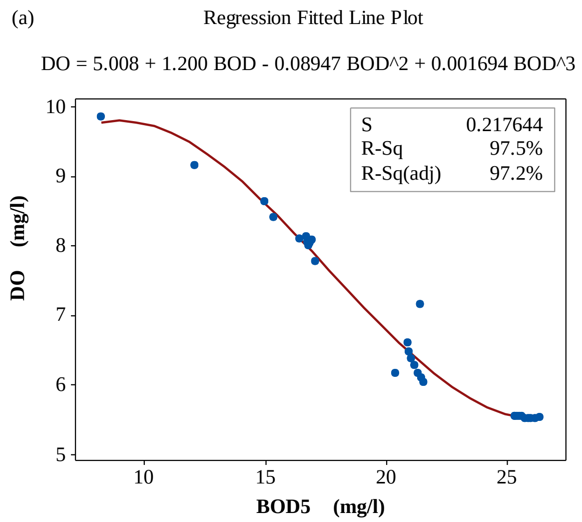


Fig. 3 The distribution of flow velocity, reaeration process and the simulated WQ parameters in terms of DO and BOD_5, along El-Salam Canal from September 2013 to August 2014.



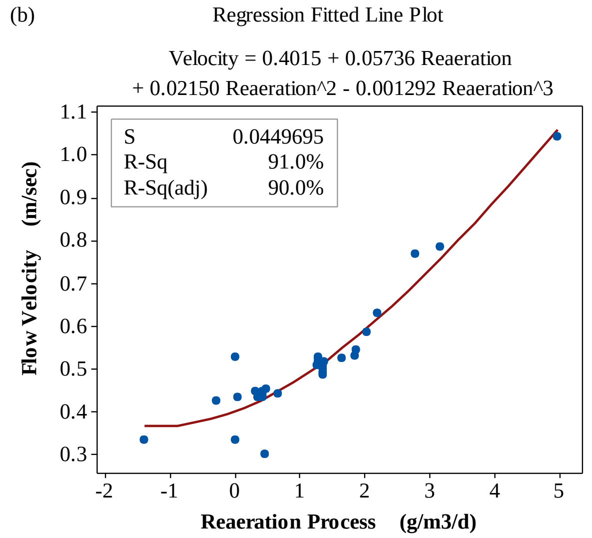


Fig. 4 The regression fitted line results between (a) DO with BOD_5 parameters, and (b) flow velocity with reaeration process values, along El-Salam Canal from September 2013 to August 2014.

5. Conclusion

This study was applied along the largest agricultural drainage water (ADW) reuse project, El-Salam Canal in Egypt. A one-dimensional HD and WQ model (MIKE 11) were developed to acquire the HD characteristics and WQ parameters (DO and BOD_5) along the canal. The calibration of HD module was applied from September 2012 to August 2013 and the verification process was from September 2013 to August 2014 along El-Salam Canal. The WQ module was developed and calibrated for the period from September 2013 to August 2014. The simulated results evidenced the reliability of the model in simulating the water quantity and WQ along the canal with a reasonable agreement between the observed and simulated data. The results illustrated that the WQ deteriorated towards the downstream of the canal due to the polluted water discharged from the El-Serw and Bahr Hadous drains. Statistical analysis was performed on the simulation results for obtaining a quantitative relationship, as regression fitted line and Pearson correlation analysis. The results showed that the DO with BOD_5 and reaeration rates with flow velocity values had a significant correlation of (r = – 0.975) and (r =

0.910), respectively. Accordingly, water velocity is an important parameter which should be taken into account for describing the water quality change.

References

[1] W. Zhi *et al.*, "From hydrometeorology to river water quality: Can a deep learning model predict dissolved oxygen at the continental scale?," *Environ. Sci. Technol.*, vol. 55, no. 4, pp. 2357–2368, 2021.

[2] J. Wu and X. Yu, "Numerical Investigation of Dissolved Oxygen Transportation through a Coupled SWE and Streeter–Phelps Model," *Math. Probl. Eng.*, vol. 2021, 2021.

[3] B. Huang *et al.*, "Quantitative study of degradation coefficient of pollutant against the flow velocity," *J. Hydrodyn. Ser. B*, vol. 29, no. 1, pp. 118–123, 2017.

[4] Z.-G. Ji, *Hydrodynamics and water quality: modeling rivers, lakes, and estuaries*. John Wiley & Sons, 2017.

[5] W. Assar, M. G. Ibrahim, W. Mahmod, and M. Fujii, "Assessing the agricultural drainage water with water quality indices in the El-Salam Canal mega project, Egypt," *Water*, vol. 11, no. 5, p. 1013, 2019.

[6] J. Liang, Q. Yang, T. Sun, J. D. Martin, H. Sun, and L. Li, "MIKE 11 model-based water quality model as a tool for the evaluation of water quality management plans," *J. Water Supply Res. Technol.*, vol. 64, no. 6, pp. 708–718, 2015.

[7] W. Assar, M. G. Ibrahim, W. Mahmod, A. Allam, A. Tawfik, and C. Yoshimura, "Effect of Water Shortage and Pollution of Irrigation Water on Water Reuse for Irrigation in the Nile Delta," *J. Irrig. Drain. Eng.*, vol. 146, no. 2, p. 5019013, 2020.

[8] H. A. A. El Gammal, "Water quality interventions case study: El-Salam Canal area," *Adv. Environ. Biol.*, vol. 10, no. 3, pp. 35–45, 2016.

[9] DHI, "MIKE 11: a modeling system for rivers and channels. Reference manual." Danish Hydraulic Institute, Hørsholm, Denmark, 2008, 2012.

[10] A. Shakibaeinia, Y. B. Dibike, S. Kashyap, T. D. Prowse, and I. G. Droppo, "A numerical framework for modelling sediment and chemical constituents transport in the Lower Athabasca River," *J. soils sediments*, vol. 17, no. 4, pp. 1140–1159, 2017.

[11] M. Salari, E. Teymouri, and Z. Nassaj, "Application of an Artificial Neural Network Model for estimating of Water Quality Parameters in the Karun River, Iran," *J. Environ. Treat. Tech.*, vol. 9, no. 4, pp. 720–727, 2021.

[12] A. Hafez, M. Khedr, K. El-Katib, H. G. Alla, and S. Elmanharawy, "El-Salaam Canal project, Sinai II. Chemical water quality investigations," *Desalination*, vol. 227, no. 1–3, pp. 274–285, 2008.

[13] A. A. Othman, S. A. Rabeh, M. Fayez, M. Monib, and N. A. Hegazi, "El-Salam canal is a potential project reusing the Nile Delta drainage water for Sinai desert agriculture: Microbial and chemical water quality," *J. Adv. Res.*, vol. 3, no. 2, pp. 99–108, 2012.

[14] A. Hafez, M. Khedr, K. El-Katib, and H. Gadallah, "Pilot scale investigation of low pressure nanofiltration and reverse osmosis membrane techniques for the treatment of El-Salaam canal water, Sinai, Egypt," *Desalin. water Treat.*, vol. 8, no. 1–3, pp. 279–285, 2009.

[15] J. J. Mocuba, "Dissolved oxygen and biochemical oxygen demand in the waters close to the Quelimane sewage discharge." The University of Bergen, 2010.

[16] C. Gualtieri, P. Gualtieri, and G. P. Doria, "Dimensional analysis of reaeration rate in streams," *J. Environ. Eng.*, vol. 128, no. 1, pp. 12–18, 2002.