STM JOURNALS

Journal of
Water Resource Engineering and Management

ISSN: 2349-4336
Volume 12, Issue 3, 2025
September–December
DOI (Journal): 10.37591/JoWREM

https://journals.stmjournals.com/jowrem

Research JoWREM

Assessment of Water Quality and Quantity Trends at Reuse Locations within the Bahr El-baqar Drainage Catchment under water Stress Reduction Scenarios

Muhammad Ahmad Abdul-Muttalib[1], Aiman El-Saadi[2]; Mahmoud Ali Refaey[3], Hossam El-Gazzar[4,*]

Abstract

Many countries face the pressing challenge of water scarcity, affecting around 20% of the global population in areas with water shortages. Egypt, one of the most populous countries in Africa and the Middle East, is severely impacted by this issue. To address this, Egypt is focusing on developing alternative water resources, including the reuse of agricultural drainage water for irrigation. In this study, the SIWARE model was employed to evaluate water quality and quantity at two key sites in the Bahr El-Baqar catchment area in the Eastern Delta: (1) the Bahr El-Baqar feeder and (2) the Bilad El-Ayad pump station. The assessment explores scenarios of reduced Eastern Delta water quotas, which may result from population growth and upstream Nile projects. The model was calibrated and validated using data from 2020 and 2021, considering factors such as soil type, hydrology, climate, and water supply. Findings indicate that at the first site, with no reduction in the water quota, average annual total dissolved solids (TDS) exceed 2000 PPM, requiring a 15.8% increase in the Eastern Delta water quota to meet Egyptian regulations Law 48/1982 and amendments in 2013. Additionally, formulas were developed to predict salinities and discharges at both reuse sites under various any reduction scenarios, offering insights for improving water management in the Bahr El-Baqar catchment area.

Keywords: Water scarcity, SIWARE model, Water management in Eastern Delta, Water quality and quantity trends, Reuse at Bahr El-Baqar catchment

*Author for Correspondence
Hossam El-Gazzar
E-mail: hossamelgzzar89@yahoo.com

[1]Assistant Professor, Civil Engineering Department, Faculty of Engineering at Shoubra, Benha University, Cairo 11629, 108 Shoubra St., Egypt;
[2]Professor, Nile Research Institute, National Water Research Centre, Delta Barrage 13621, Egypt;
[3]Professor, Civil Engineering Department, Faculty of Engineering at Shoubra, Benha University, Cairo 11629, 108 Shoubra St., Egypt;
[4]Assistant Researcher, Drainage Research Institute, National Water Research Centre, Delta Barrage13621, Egypt;

Received Date: August 05, 2025
Accepted Date: August 09, 2025
Published Date: August 14, 2025

Citation: Muhammad Ahmad Abdul-Muttalib, Aiman El-Saadi; Mahmoud Ali Refaey, Hossam El-Gazzar. Assessment of Water Quality and Quantity Trends at Reuse Locations within the Bahr El-baqar Drainage Catchment under water Stress Reduction Scenarios. Journal of Water Resource Engineering and Management. 2025; 12(3): 1–11p.

INTRODUCTION

Water scarcity arises when the demand for water surpasses the available supply or when water quality is insufficient to meet the needs of both people and the environment. Factors contributing to this issue include climate change, population growth, urban expansion, pollution, overuse, and ineffective water management. This scarcity has significant impacts on public health, food security, economic growth, societal stability, and environmental sustainability [1-5]. As a result, countries are striving to create effective water management strategies to mitigate this challenge [6-11].

Egypt, with a population exceeding 100 million, receives annual allocation of 55.5 billion cubic meters (BCM) which is below the World Business Council for Sustainable Development's threshold of 1000 cubic meters per capita per year, indicating water scarcity [12]. To address this shortfall, unconventional water sources are crucial for irrigation [13-17]. Egypt produces approximately 17 billion cubic meters (BCM) of agricultural drainage water each year, with over three-quarters of it being discharged into the Mediterranean Sea [18]. Reuse of drainage water in irrigation purposes is considered one of the most important unconventional water resources in Egypt [19-22].

Water management models are essential for evaluating the suitability of agricultural drainage water for irrigation [23-26]. Allam et al. (2015) assessed the feasibility of using agricultural drainage water (ADW) for irrigation in the Gharbia drain, Middle Delta, Egypt, between August 2009 and July 2012, using the QUAL2Kw model. They focused on two main aspects: the first was the quantity of ADW available for reuse to meet irrigation water needs, and the second involved comparing the quality of reused ADW with Egypt's irrigation standards set by Environmental Law 48/1982 and its modification in 2013 [27]. The findings showed that water quality ranged from good to very good in the summer, but from fair to good in the winter. However, water quantity was considered to range from moderate scarcity to no scarcity in both seasons. Allam et al. (2016) introduced a framework by applying QUAL2Kw model for reusing agricultural drainage water in irrigation. This framework aimed to determine the quantities of agricultural drainage water for reuse at seven different locations. The findings revealed that the reuse quantities could reach 36.3% of the available agricultural drainage water during summer and 40.4% in winter. These were corresponded to 30.8% and 29.9% of the fresh irrigation water required during each respective season in the drainage basin. EL-salam canal was investigated using the MIKE model. According to the results, the water quality of El-Salam Canal is considered suitable for irrigation in regions facing water scarcity. Additionally, the existing mixing ratio of agricultural drainage water and Nile fresh water (1:1) is adequate to achieve acceptable water quality [24]. The SIWARE module assessed the impact of unofficial drainage water reuse on water usage in the Zarqun and Shubrakhit drainage catchments. Results showed a water deficit, leading farmers to reuse drainage water unofficially, the electrical conductivity (EC) of the unofficially reused water ranges between 2 and 3.5 ds/m, imposing limitations on the types of crops that can be grown [12]. In El-Behira governorate, facing water scarcity and high salinity, the SIWARE module evaluated water balance and reuse implications. Based on the simulation results, the unofficial reuse of drainage water in 2015 increased by approximately 7.3% compared to 2014. Additionally, the total simulated unofficial reuse volume is approximately three times that of the official reuse in the study area. Recommendations include improving water use efficiency and monitoring water quality [28].

Shaban (2020) Investigate the variations in the existing drainage water reuse patterns by analyzing the discharge volumes and their associated salinities recorded in the Nile Delta regions since 1984. The findings suggest that both the discharge from drainage water reuse and salinity levels have shown upward trends in the Eastern Nile Delta. The findings also showed that it is possible to increase the mean discharge of drainage water reuse up to 101% in the Eastern Delta; however, this increase would be accompanied by a rise in drainage water reuse salinity levels of up to 39.5% [29].

As a result, the aim of this study was to evaluate the water quality and quantity under various water shortage scenarios at the two reuse sites in the Bahr El-Baqar drainage catchment area. This region houses the largest wastewater treatment plant in the world, which began operating in the Eastern Delta in (2021), treating approximately 5.6 million cubic meters (MCM) of drainage water daily [17].

METHODOLOGY

Study area

The study area is the Eastern Delta, including two locations for water reuse in Bahr El-Baqar drainage catchment. The first location is the Bahr El-Baqar feeder (BBF) at coordinates (32.30°E, 31.02°N), where it receives water from the Bahr El-Baqar drain meeting the Om El-Reesh drain and crossing Suez Canal through a syphon before being directed to the Bahr El-Baqar waste water treatment plant (BB WWTP). The second location is at the Bilad El-Ayad pump station (BAP), situated at (31.65°E,

Journal of Water Resource Engineering and Management
Volume 12, Issue 3
ISSN: 2349-4336

30.54°N), where the Bilad El-Ayad drain reuses some of its water with Wadi Canal. The processes of calibration and validation were conducted at the South Port Said Pump Station (C.V.1) and the South of Al-Hussainiya Plain pump station (C.V.2), respectively, as illustrated in Figure 1.

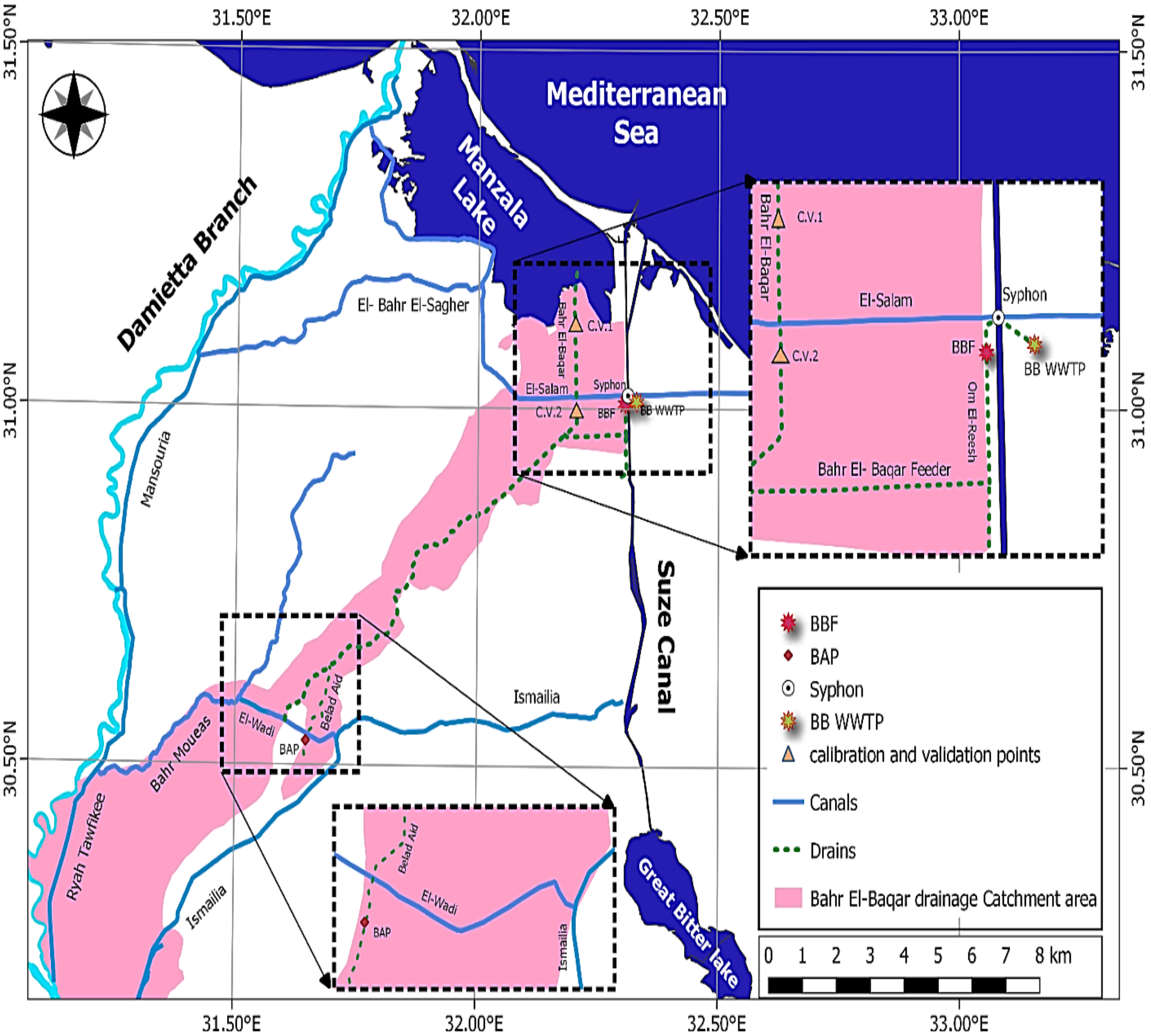


Figure 1. The Eastern Delta, which includes the Bahr El-Baqar drainage catchment area and its reuse sites, along with the locations for calibration and validation

Description of the Applied Model

The research area was simulated using SIWARE (Simulation of Water Management in the Arab Republic of Egypt), a modeling tool designed to forecast upcoming changes resulting from various factors such as variations in water management practices, agricultural adjustments, or modifications in hydraulic, hydrological, and meteorological conditions [30]. This comprehensive model for the Nile Delta integrates all relevant physical and functional relationships. Merging drainage data from representative field plots, an exclusive algorithm calculates the total drainage output for each subarea. The model segments the study area into smaller areas known as calculation units (CUs). The model divides canals into nodes and drains into sections, linking each CU to a specific node for water intake and a section for drainage. Additionally, the model also considered the farmer behavior. When freshwater is insufficient, farmers often resort to unofficial reuse, irrigating their fields with the nearest available water source, such as drainage water. In contrast, official reuse involves blending drainage water with freshwater in specific proportions at reuse pump stations, according to drainage water quality and standards set by the Ministry of Water Resources and Irrigation (MWRI). This previous schematic representation is illustrated as in Figure 2.

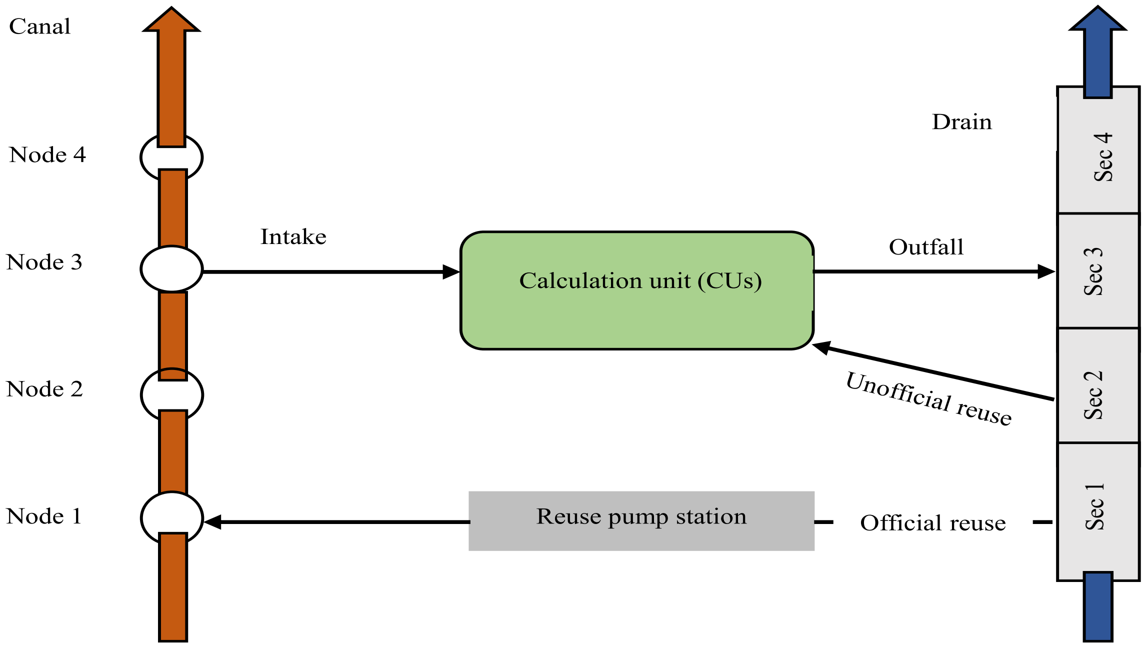


Figure 2. Operational framework of the SIWARE model.

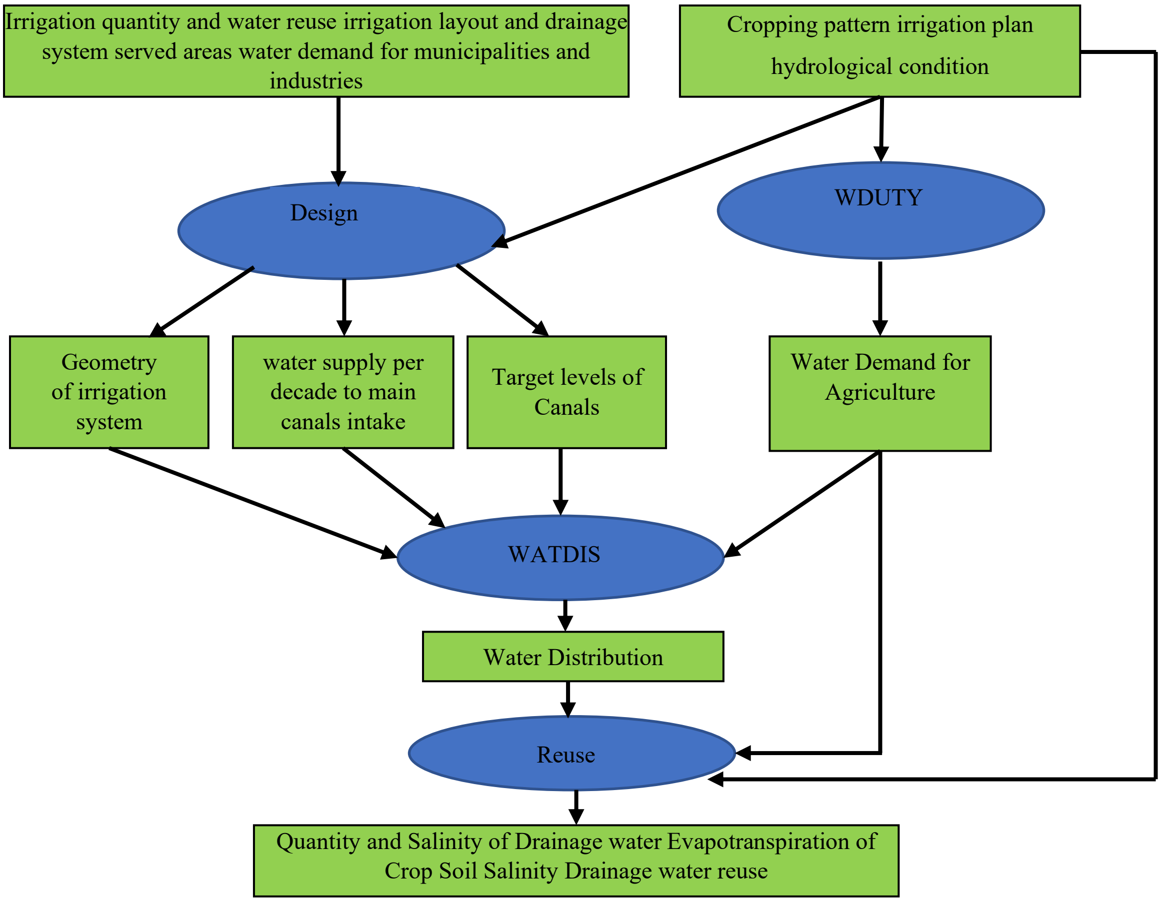


Figure 3. The SIWARE simulation model and its sub-models.

The SIWARE comprises four sub-models with specific inputs and outputs, as illustrated in Figure 3. The Design module calculates the physical dimensions of the irrigation system based on layout, areas served by canals, and municipal and industrial water needs, while also maintaining target water levels at control structures by considering cropping patterns, irrigation schedules, and planned drainage water reuse. The water duty (WDUTY) module addresses agricultural conditions, factoring in crop patterns, irrigation schedules, soil properties and water conditions. The water distribution (WATDIS) module manages water allocation to main canals, autonomously selecting time steps based on discharge changes. The REUSE module integrates water management processes, starting with WATDIS's irrigation water distribution and, if the supply is insufficient for agricultural demand, uses drainage water to supplement irrigation as unofficial reuse.

Data collection and model setup

The input data for the model were sourced from multiple organizations. The Eastern Delta region was firstly divided into 115 CUs, each served by one canal and one drain, with consistent soil properties within each unit, as shown in Figure 4. The Ministry of Agriculture and Land Reclamation (MALR) furnished crop pattern data and fraction cultivated area for the Marakez in the Eastern Delta, which was intersected for the CUs using Quantum Geographic Information System (QGIS) to determine the percentage of cultivated area for CUs, as depicted in Figure 5. All crops were represented in the model by 15 main crop types. This number was selected by categorizing crops with similar characteristics, such as irrigation salinity, water ratio, crop height, soil cover, maximum ponding, and rooting depth. MALR also supplied water duty information for these crops. The model incorporated the total annual water supply to the Eastern Delta and the water quantities for canals in this study region, as provided by MWRI. Each canal received its allocated share based on irrigation rotations, with each month divided into three decades, resulting in 36 decades per year. Additionally, the Drainage Research Institute (DRI) provided data on the quantity and salinity of water reused officially in 2020 and 2021, which was applied to the model for all reuse stations in the Eastern Delta according to their respective decades throughout the year. The Ground Water Research Institute (GWRI) contributed data on groundwater abstractions, aquifer thickness, clay cap thickness, hydraulic permeability, piezometric head, and aquifer salinity for all CUs. Furthermore, average meteorological data over ten years, such as precipitation and evaporation, were directly employed in the model. Other data, including solar radiation, average temperature, relative humidity, sunshine hours, wind speed, and precipitation, were analyzed before being applied in the model to determine the maximum evaporative demand relative to crop height and the reduction factor for incomplete soil cover using the Rijtema approach [31].

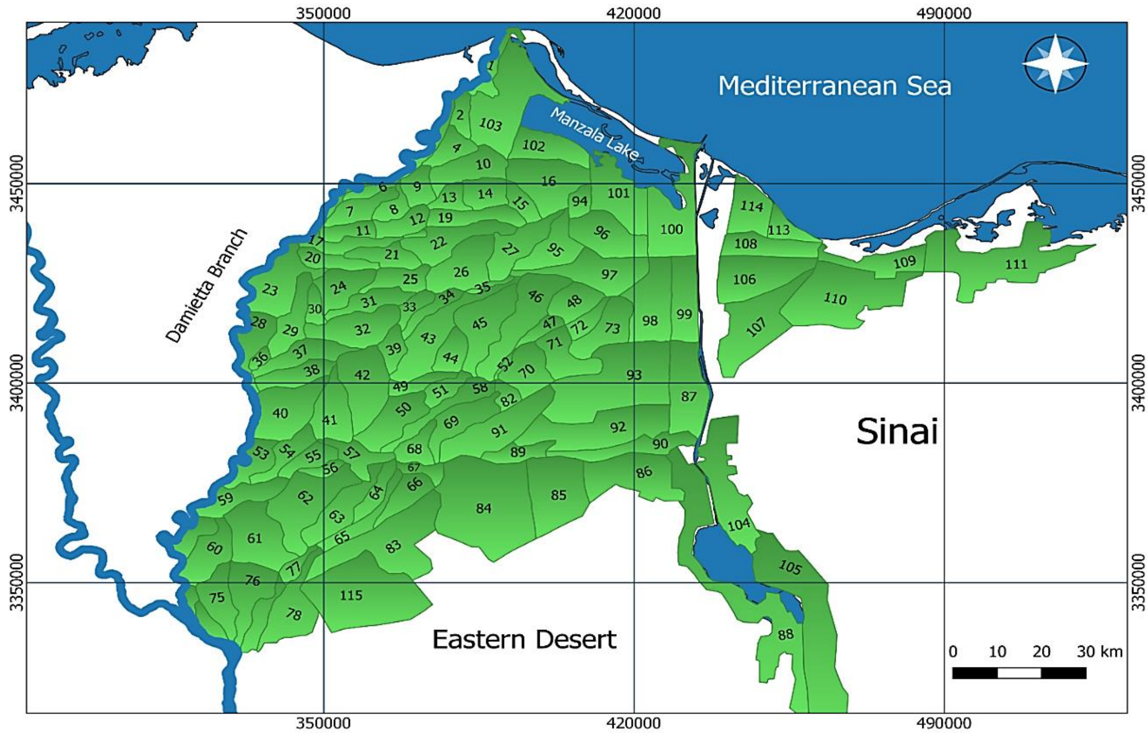


Figure 2. Eastern Delta and its calculation units (CUs).

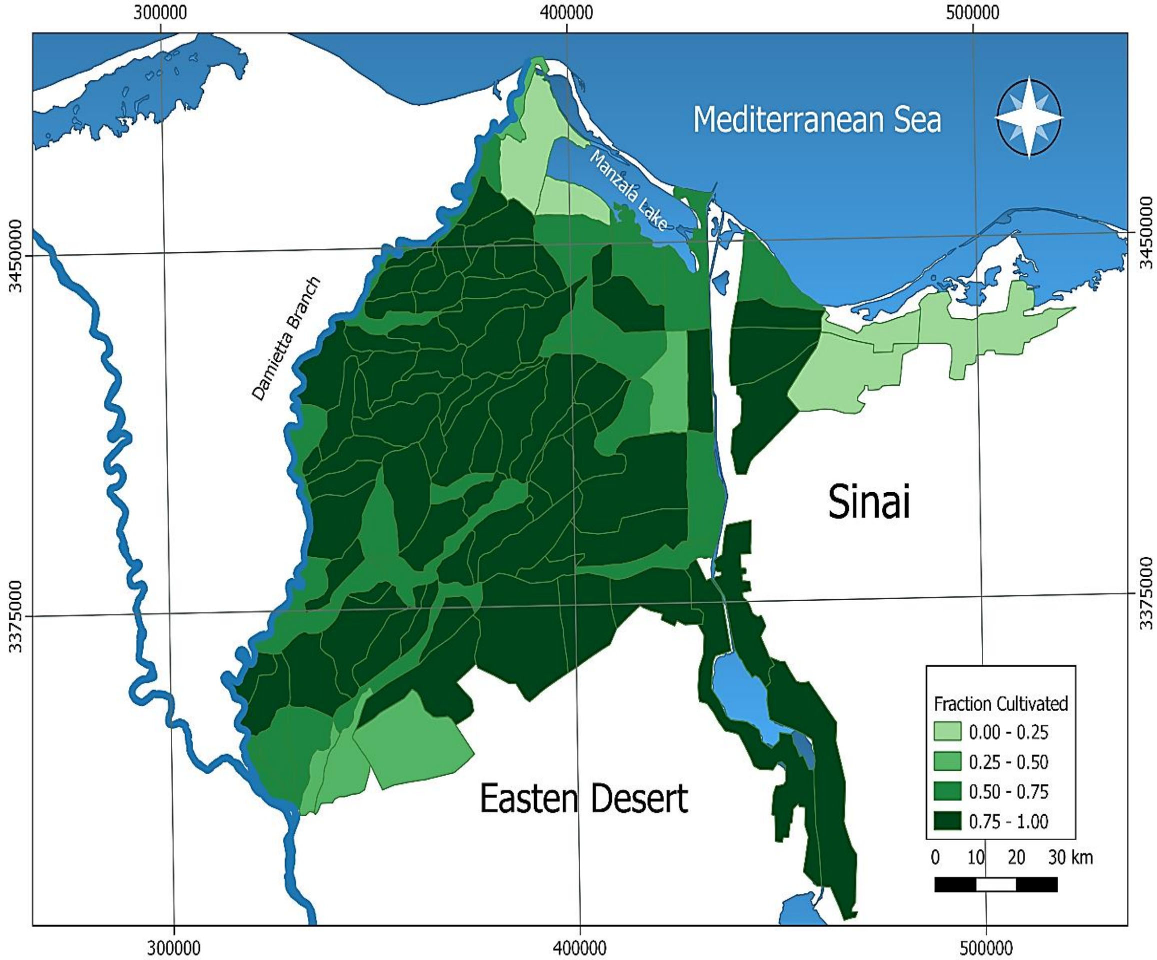


Figure 3. The fraction cultivated per (CUs) in Eastern Delta at calibrated year (2020).

RESULTS AND DISCUSSION

Calibration and Validation

The model underwent calibration using the 2020 dataset as a baseline and subsequent validation using data collected in 2021. Simulated monthly average discharge in (m^3/s) and salinity which represented by EC in (ds/m) were plotted and compared against observed values. The monthly average deviation ($Av._{dev.}$), defined by Equation 1, served as the comparison parameter between modeled and observed values. This performance criterion, with allowed average monthly deviations of 30% for discharge and 50% for salinity been determined by the Steering Committee for the Reuse of Drainage Water Project from DRI, MWRI and Egyptian government [31, 32], assessed how well SIWARE simulated results aligned with drainage water measurements.

$$Av._{dev.} = 100 * \frac{\sum(P_m - P_c)}{\sum\left(\frac{P_m + P_c}{2}\right)} \quad \text{Equation 1}$$

Where P_m and P_c are the measured and simulated values, respectively, for both discharge and salinity values.

The calibration and validation results are displayed for the two drainage locations C.V.1, as shown in Figure 6, and C.V.2, as shown in Figure 7. The data reveals that, for both stations, the maximum average deviation during the calibration year 2020 and the validation year 2021 did not exceed 12.4% for discharge and 20.59% for salinity. This indicates that the average deviation at both stations remains within an acceptable range.

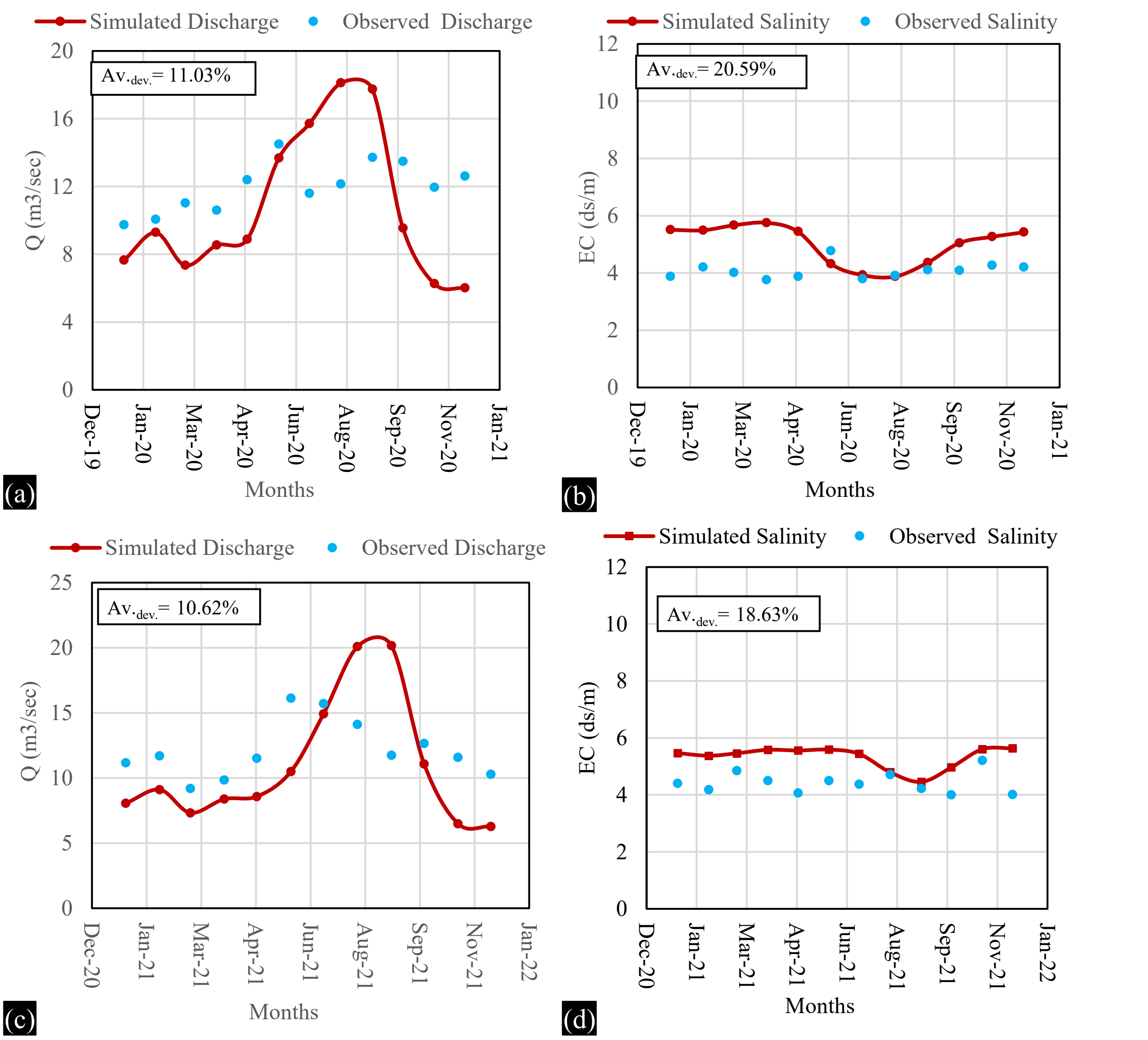
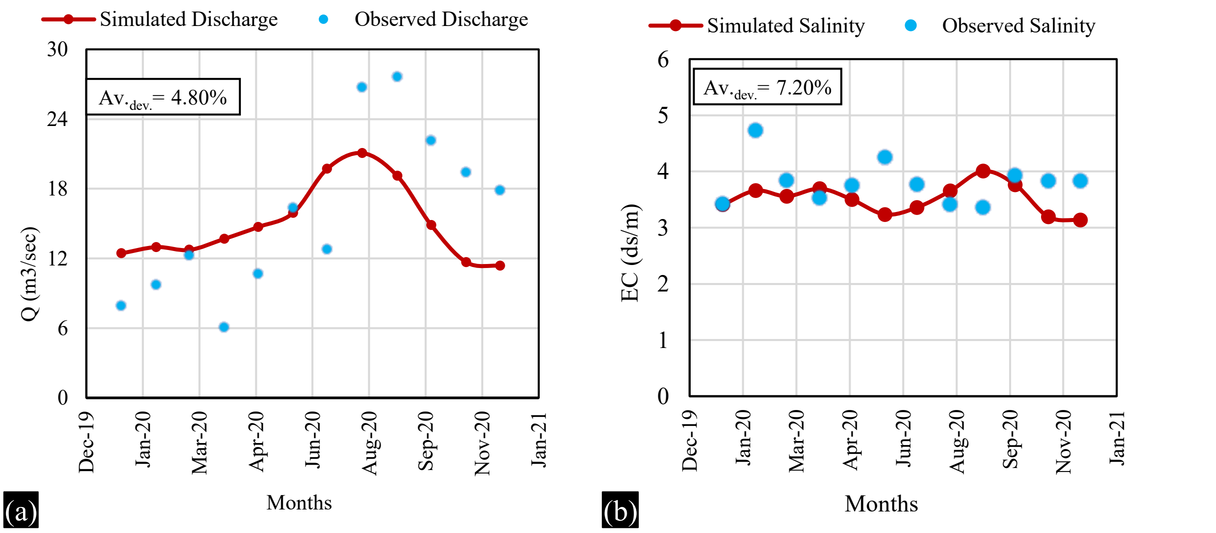


Figure 6. The comparison between the simulated and observed monthly average values at C.V.1 includes: (a) discharge for the year 2020, (b) salinity for the year 2020, (c) discharge for the year 2021, and (d) salinity for the year 2021.



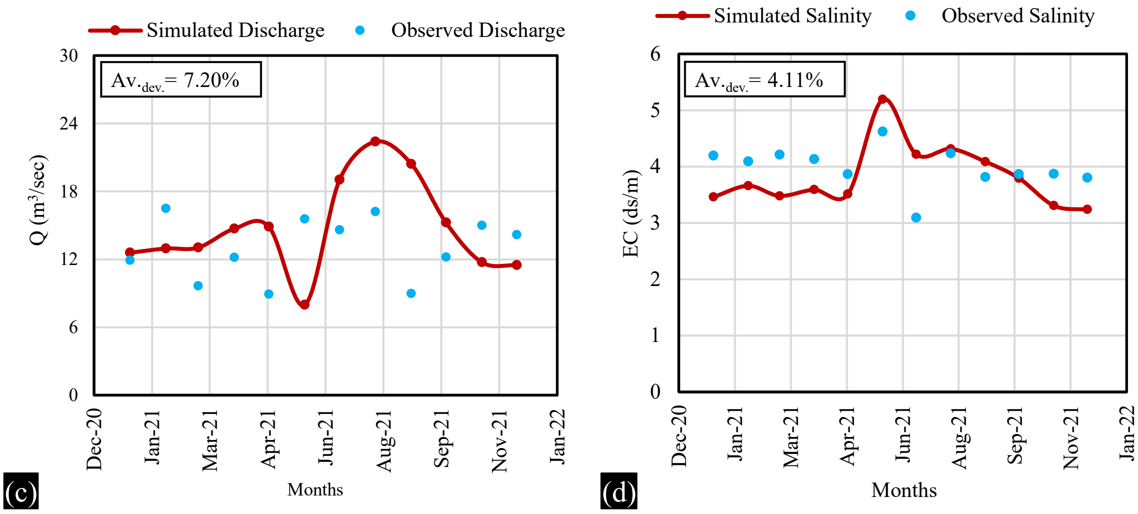


Figure 7. The comparison between the simulated and observed monthly average data at C.V.2 covers: (a) discharge in 2020, (b) salinity in 2020, (c) discharge in 2021, and (d) salinity in 2021.

Effect of decreasing water allocation in the Eastern Delta on the water quantity and quality at reuse locations

The average annual discharge and salinity were graphed against varying reductions in the Eastern Delta water quota, ranging from 5% to 50%, for the two reuse sites at Bahr El-Baqar drainage catchment area. The results for BBF, as depicted in Figure 8 (a), reveal that with no reduction in the water quota, the total dissolved solids (TDS) reach 2200 PPM, exceeding the acceptable limit of 2000 PPM as per Egyptian regulations for reusing drainage water under Law 48/1982 and its amendments in 2013 [27]. To stay within the limit, an increase of 15.8% in the Eastern Delta water quota is required. Furthermore, under a 50% reduction scenario, TDS sharply rises beyond 3000 PPM. Figures 8 (a) and (b) indicate that a 50% reduction in the water quota leads to a 36% increase in TDS and a 47% decrease in discharge. Both relationships are well-fitted by exponential trendlines with a correlation of determination (R^2) almost equal to 0.98. Consequently, Equations 2 and 3 derived from these relationships can predict salinities and discharges, respectively, at BBF, under any reduction scenario in the water quota. (where x: is the percentage of reduction in water quota).

$$TDS_{BBF} = 2198.7 \cdot e^{0.006x} \qquad \text{Equation 2}$$
$$Q_{BBF} = 59.62 \cdot e^{-0.01x} \qquad \text{Equation 3}$$

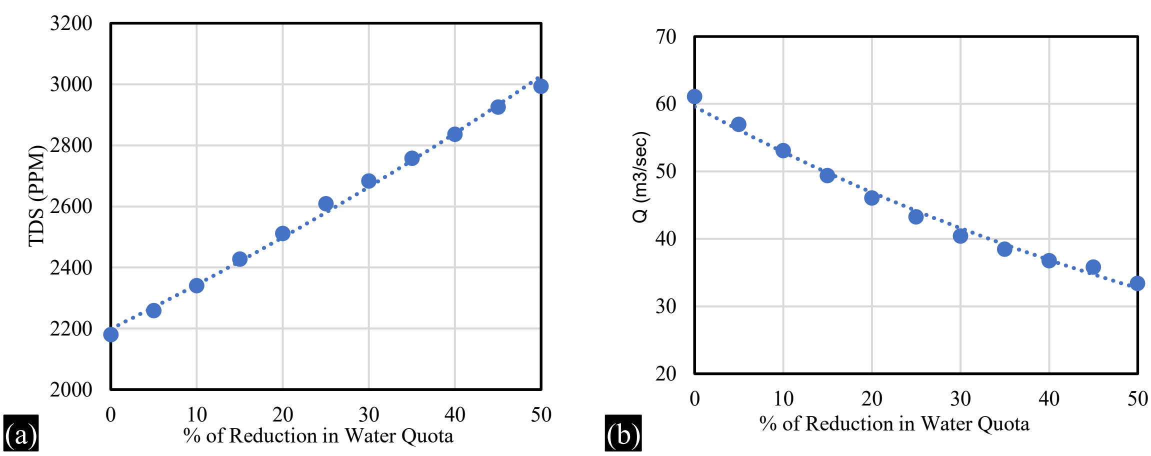


Figure 8. (a) Relation between TDS in (PPM) and the reduction percentage scenarios in Eastern Delta water quota at BBF; (b) Relation between discharge in (m^3/s) and the reduction percentage scenarios at BBF

Similarly, for BAP, as shown in Figure 9 (a), the outcomes demonstrate that in all scenarios of the reduction water quota, the TDS values consistently stay below the accepted limit of 2000 PPM. Furthermore, the TDS value increases from 550 PPM to 640 PPM when the reduction in the water quota increases from 0% to 50%, respectively. The findings also indicate, as portrayed in Figure 9 (a) and (b), that a 50% increase in the reduction percentage of the water quota results in a 16.4% increase in TDS and a 45% decrease in discharge. Both relationships are almost represented by exponential trendlines with a correlation of determination (R^2) approximately equal to 0.98. Equations 4 and 5 derived from these relationships can forecast both salinities and discharges at BAP under any reduction scenario in the water share. (where x: is the percentage of reduction in water quota).

$TDS_{BAP} = 554.73 \cdot e^{0.003x}$ Equation 4
$Q_{BAP} = 4.72 \cdot e^{-0.011x}$ Equation 5

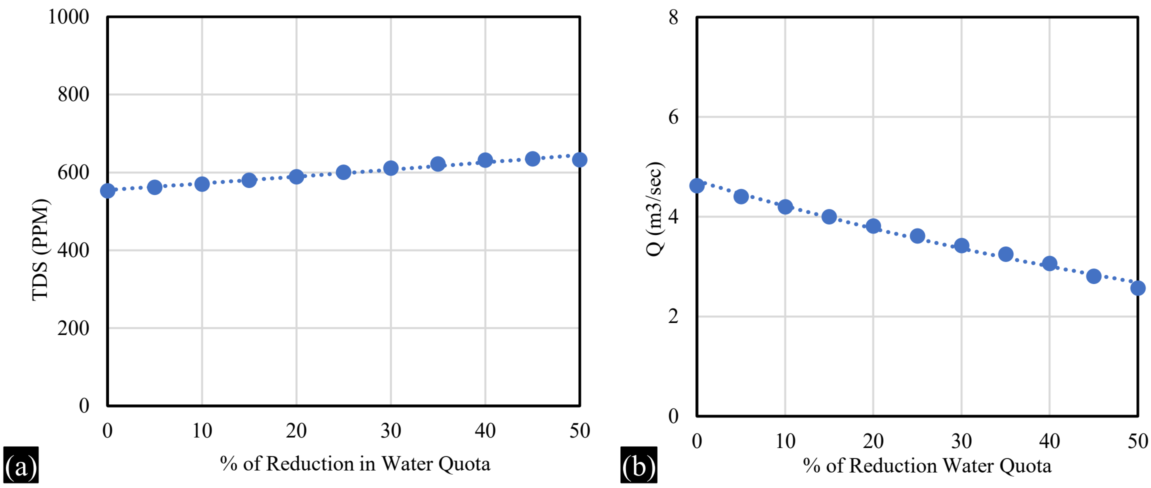


Figure 9. (a) Relation between TDS in (PPM) and the reduction percentage scenarios in water Quota at BAP; (b) Relation between discharge in (m^3/s) and the reduction percentage scenarios in water Quota at BAP

CONCLUSIONS

The SIWARE model was used to simulate the region of Eastern Delta to assess trends in water quality and quantity at the two crucial reuse locations, BBF and BAP, in the Bahr El-Baqar catchment area. The model was calibrated and validated based on the collected data related to soil type, hydrological characteristics, climate, and water supply in the years 2020 and 2021. The results indicate that BBF exhibits TDS exceeding 2000 PPM, necessitating a 15.8% increase in Eastern Delta water quota to meet environmental Law 48/1982 and amendments in 2013. In addition, it was found that, the A 50% reduction in water quota sharply raises TDS beyond 3000 PPM with a 36% increase and 47% decrease in discharge. The findings also reveal that the salinity at BAP consistently stays below 2000 PPM, but a 50% reduction in water quota leads to a 16.4% TDS increase and 45% discharge decrease. Additionally, equations have been developed to predict salinities and discharges for both reuse sites under various reduction scenarios in the Eastern Delta water quota. This can offer valuable insights for enhancing water management in the Bahr El-Baqar catchment area.

REFERENCES

1. Ungureanu, N., Vlăduț, V., & Voicu, G. (2020). *Water scarcity and wastewater reuse in crop irrigation. Sustainability (Switzerland)*, *12*(21), 1–19. https://doi.org/10.3390/su12219055.
2. Amali, A. A., Mersha, A. N., Nofal, E. R., Murray, K., Norouzi, S., Saboory, S., Salo, H., Chevuru, S. R., Sarai Tabrizi, M., Reddy, P. K., Abdullahi, A. O., Farahani, H., Kolhe, P., Dowlati Fard, R., Salik, A. W., Hussein, A. H., Najafi, H., Poormoghadam, M., & Adiaha, M. (2021). *Non-conventional sources of agricultural water management: Insights from young professionals in the*

*irrigation and drainage sector**. *Irrigation and Drainage*, 70(3), 524–540. https://doi.org/10.1002/ird.2495.

3. Fito, J., & Van Hulle, S. W. H. (2021). *Wastewater reclamation and reuse potentials in agriculture: towards environmental sustainability. Environment, Development and Sustainability*, 23(3), 2949–2972. https://doi.org/10.1007/s10668-020-00732-y.
4. Schwaller, C., Keller, Y., Helmreich, B., & Drewes, J. E. (2021). *Estimating the agricultural irrigation demand for planning of non-potable water reuse projects. Agricultural Water Management*, *244*(September 2020). https://doi.org/10.1016/j.agwat.2020.106529.
5. Abou-Shady, A., Siddique, M. S., & Yu, W. (2023). *A Critical Review of Recent Progress in Global Water Reuse during 2019–2021 and Perspectives to Overcome Future Water Crisis. Environments* - MDPI, 10(9). https://doi.org/10.3390/environments10090159.
6. Wade Miller, G. (2006). *Integrated concepts in water reuse: Managing global water needs*. *Desalination*, *187*(1–3), 65–75. https://doi.org/10.1016/j.desal.2005.04.068.
7. Procházka, P., Hönig, V., Maitah, M., Pljučarská, I., & Kleindienst, J. (2018). *Evaluation of water scarcity in selected countries of the Middle East. Water (Switzerland)*, *10*(10). https://doi.org/10.3390/w10101482.
8. Molden, D. (2020). Scarcity of water or scarcity of management? *International Journal of Water Resources Development*, *36*(2–3), 258–268. https://doi.org/10.1080/07900627.2019.1676204.
9. Hristov, J., Barreiro-Hurle, J., Salputra, G., Blanco, M., & Witzke, P. (2021). *Reuse of treated water in European agriculture: Potential to address water scarcity under climate change. Agricultural Water Management*, *251*. https://doi.org/10.1016/j.agwat.2021.106872.
10. Ethaib, S., Zubaidi, S. L., & Al-Ansari, N. (2022). *Evaluation water scarcity based on GIS estimation and climate-change effects: A case study of Thi-Qar Governorate, Iraq*. *Cogent Engineering*, *9*(1). https://doi.org/10.1080/23311916.2022.2075301.
11. Kaczmarek, N., Mahjoubi, I., Benlasri, M., Nothof, M., Schäfer, R. B., Frör, O., & Berger, E. (2023). *Water quality, biological quality, and human well-being: Water salinity and scarcity in the Draa River basin, Morocco*. *Ecological Indicators*, *148*. https://doi.org/10.1016/j.ecolind.2023.110050.
12. El-moneim, A. A. B. D., Allah, A. A. B. D., Hassan, A., & El-fotouh, S. A. (2018). *Impacts Of Unofficial Water Reuse In Edko Drain Catchment , Western* 1 Introduction 2 Material and Methods.
13. Elshemy, M. (2019). *Review of Technologies and Practices for Improving Agricultural Drainage Water Quality in Egypt*. In *Handbook of Environmental Chemistry* (Vol. 75, pp. 163–188). Springer Verlag. https://doi.org/10.1007/698_2017_78.
14. Refaey, A. El. (2020). *Drainage Water Quality Enhancement for Safe Irrigation Reuse and Algal Blooms Mitigation*. July. https://www.researchgate.net/publication/343083641.
15. Tawfik, M. H., Hoogesteger, J., Elmahdi, A., & Hellegers, P. (2021). *Unpacking wastewater reuse arrangements through a new framework: insights from the analysis of Egypt*. *Water International*, *46*(4), 605–625. https://doi.org/10.1080/02508060.2021.1921503.
16. Abd-Elaty, I., Kuriqi, A., & Shahawy, A. El. (2022). *Environmental rethinking of wastewater drains to manage environmental pollution and alleviate water scarcity*. *Natural Hazards*, *110*(3), 2353–2380. https://doi.org/10.1007/s11069-021-05040-w.
17. Khairy, W. M. (2022). *the National and International Water Policies With Focus on the Drainage Water Reuse Practices and the Mega Water Projects*. *International Journal of Research - GRANTHAALAYAH*, *10*(9), 42–68. https://doi.org/10.29121/granthaalayah.v10.i9.2022.4754.
18. Allam, A., Fleifle, A., Tawfik, A., Yoshimura, C., & El-Saadi, A. (2015). *A simulation-based suitability index of the quality and quantity of agricultural drainage water for reuse in irrigation*. *Science of the Total Environment*, *536*, 79–90. https://doi.org/10.1016/j.scitotenv.2015.07.029.
19. Mostafa, H., El-Gamal, ; F, & Shalby, A. (2005). *Reuse of low quality water in egypt*.
20. Abdel-Shafy, H. I., & Mansour, M. S. M. (2013). *Sustainable Sanitation Practice Overview on water reuse in Egypt: Present and Future Use of treated wastewater is of tremendous potential importance to Egypt, particularly for restricted irrigation and forest trees*.

21. Fleifle, A. E., Saavedra Valeriano, O. C., Nagy, H. M., Elfetiany, F. A., Tawfik, A., & Elzeir, M. (2013). *Simulation-Optimization Model for Intermediate Reuse of Agriculture Drainage Water in Egypt*. *Journal of Environmental Engineering*, *139*(3), 391–401. https://doi.org/10.1061/(asce)ee.1943-7870.0000605.
22. Barnes, J. (2014). Mixing waters: *The reuse of agricultural drainage water in Egypt*. *Geoforum*, *57*, 181–191. https://doi.org/10.1016/j.geoforum.2012.11.019.
23. Wahba, M. A. S. (2017). *Assessment of Options for the Sustainable Use of Agricultural Drainage Water For Irrigation in Egypt by Simulation Modelling*. *Irrigation and Drainage*, *66*(1), 118–128. https://doi.org/10.1002/ird.2029.
24. Allam, A., Tawfik, A., Yoshimura, C., & Fleifle, A. (2016). *Simulation-based optimization framework for reuse of agricultural drainage water in irrigation*. *Journal of Environmental Management*, *172*, 82–96. https://doi.org/10.1016/j.jenvman.2016.02.022.
25. Assar, W., Ibrahim, M. G., Mahmod, ; Wael, Allam, A., Tawfik, A., & Yoshimura, C. (2019). *Effect of Water Shortage and Pollution of Irrigation Water on Water Reuse for Irrigation in the Nile Delta*. https://doi.org/10.1061/(ASCE)IR.1943.
26. Ramadan, E. M., Shalash, O. S., Fahmy, M. R., & Abdel-Aal, G. M. (2019). *Integrated water resource management in Sharkia Governorate, East Nile Delta using numerical evaluation of water management strategies*. Alexandria Engineering Journal, 58(2), 757–771. https://doi.org/10.1016/j.aej.2019.06.006.
27. MWRI. (2013). The Protection of the Nile River and Its Waterways from Pollution. Decree of Water Resources and Irrigation Ministry no. 92 for 2013 for the Executive Regulation of Law 48/1982, 92/2013. In Ministry of Water Resources and Irrigation, Egypt.
28. El-Moneim, A. A., Hassan, A. A., El-Fotouh, S. A., El-Saadi, A., & Abdallah, A. (2020). *Drainage Water Reuse under Water Scarcity. International Journal of Engineering and Advanced Technology*, 9(3), 1525–1533. https://doi.org/10.35940/ijeat.b4254.029320.
29. Shaban, M. (2020). *Drainage water reuse in the Nile Delta of Egypt: Fitting density functions and assessing temporal trends**. *Irrigation and Drainage*, *69*(4), 788–805. https://doi.org/10.1002/ird.2456.
30. DRI, & Sc-dlo. (1995). *Reuse Of Drainage Water In The Nile Delta ; Monitoring , Modelling And Analysis*.
31. S.T. Abdel Gawad, M.A. Abdel Khalek, D. Boels, D.E. El Quosy, C.W.J. Roest, P. E. R. and M. F. R. S. (1991). *Reuse Report 30. 30.*
32. El-Moneim, (2021). *Sustainable Water Resources Management in Western Nile Delta* [Doctor of Philosophy]. University of Ain Shams.

