Effectiveness of dredging and drains' treatment on water quality of Rosetta branch

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ABSTRACT

Rosetta Branch of Nile River in Egypt receives drainage water from five agricultural drains deteriorating its water quality. Since the branch is used for irrigation and municipal purposes, its water quality should be enhanced. Hence, the current paper aimed at providing the most effective intervention to improve the branch water quality. Preventing drainage disposal was excluded due its significance to downstream users. The paper investigated the impacts of drains' treatment and branch dredging on hydrodynamics and water quality. The branch was numerically simulated using HECRAS model, and calibrated using measured water levels and quality parameters. The paper selected constructed wetlands as the most suitable method for drainage treatment based on conditions of study area. SUBWET model predicted optimal designs of wetlands achieving the desired treatment efficiency. SUBWET model was calibrated with experimental wetlands at Delta Barrage. Results showed that 1-m dredging dropped water surface elevations by 22 to 50 cm. Dredging had no significant changes in the backwater zone of Edfina Barrage at the branch end except for the maximum flow case. Simulation of dissolved oxygen and ammonium showed that dredging and treatment improved water quality. Drains' treatment by constructed wetlands with selected designs was much more effective than dredging.

Keywords: Drainage treatment, Dredging, HEC-RAS, Rosetta Branch, SUBWET

1. Introduction

Egypt is as an arid country that depends on the Nile River providing 93% of the country's conventional water resources [1]. Rosetta Branch of Nile River has a total length of 256 km from the Delta Barrage to its disposal to the Mediterranean Sea. It receives drainage water of five agricultural drains transporting their water from intensive drainage networks. Many studies showed the negative impacts of drainage water disposal on the water quality of Rosetta Branch [2-4]. The deterioration of branch water quality is one of the most serious environmental threats to public health and environment in Egypt, as the branch water is the main source for irrigation, municipal and industrial purposes in the western side of Nile Delta. Therefore, proper, science-based, and implementable interventions should be provided to decision makers.

Worldwide, efforts for water quality monitoring and enhancement within watersheds were exerted. Components of spatial and

temporal variation in water quality of Potomac River, USA receiving treated sewage effluent were studied. This study also determined the most effective use of future monitoring resources [5]. Impact of tannery effluents on the Fratta-Gorzone River, Italy was studied through sediment analysis, which showed that the concentrations exceeded national and international sediment quality standards [6]. The study showed that pumping of dilution water from Adige River into the Fratta-Gorzone River did not produce the expected contaminant dilution effect. Groundwater in Indus Delta, Pakistan was analyzed for domestic and irrigation purposes [7]. Analysis results showed the unsuitability of most of the delta's water for drinking and agricultural purposes. Thus, this study recommended that wastewater should be properly treated before its use. In Cilutung watershed in Indonesia, the impact of agricultural land use on the rivers' water quality was also investigated according to water quality indices [8]. The results showed that water quality was affected by land use spatially and rivers' discharge temporally.

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Received September 20, 2020 Accepted December 15, 2020

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From a number of studies worldwide, it can be concluded that the common policies for surface water quality improvement are either pollutants' prevention and treatment, or dredging of bed sediments [9-11]. The agricultural drainage disposal into Rosetta Branch cannot be prevented, since this water is a huge volume of water covering a significant part of total irrigation demand for downstream users. Treatment of drainage water before disposal into the branch might be one intervention. But, selection of the applicable treatment method for the intensive network of drains in the study area is still a debatable issue. There are no sufficient decentralized treatment systems that can collect all drainage water from the network of subsurface and open drains on the farm level and secondary drains ending up with the five main drains which flow into Rosetta Branch.

In the latest few years, there have been emerging new low-cost methods for reducing the environmental hazards of wastewater. Filters from kaolin clay and jute fibers were manufactured, which can be provided for decreasing chemical parameters from water [12]. Ceramic Filters were also presented for water treatment [13-15]. Waste burial using plasma incinerator reactors are another new method for eliminating the emissions of environmental pollutants [16].

Due to the conditions of irrigation catchments of the five main drains, none of the above interventions are sufficient for enhancing the water quality of Rosetta Branch. Decentralized drainage treatment cannot achieve the full treatment of all drainage water. The current paper emphasizes that the centralized treatment of the five main drains as well as dredging of Rosetta branch are the most proper interventions.

The current paper is focused on constructed wetlands (CWs) as the only effective means for agricultural non-point pollution [16-18], and as the only proper method for treatment of drainage disposing into Rosetta Branch. Dredging of sediments with attached pollutants from aquatic environment has positively impacted the environment [19-21], and therefore, dredging of Rosetta Branch might be also a potential intervention for improving its water quality. According to the authors' knowledge, no studies were found on quantifying the science-based effectiveness of both interventions. Therefore, the main objective of current study is to quantify and compare the effectiveness of drains' treatment and bed dredging on the water quality of Rosetta Branch.

In order to achieve this objective, the current paper provides the methodology based on description of study area, data collection, HECRAS modeling of Rosetta Branch, and SUBWET modeling for selecting designs of CWs. Previous numerical modeling of water quality along Rosetta Branch has shown accurate results compared with field data using a number of models including: Mike11 and HEC-RAS [22, 23]. But nevertheless, the current paper provides the calibration process of the current case. To the authors' knowledge, SUBWET model has never been used for design of CWs under Egypt's conditions. Hence, the current paper conducts the calibration process for SUBWET model by simulating actual constructed wetlands. Then, the paper presented the comparison results between the effectiveness of drains' treatment and dredging. The effect of dredging on the hydrodynamics of Rosetta Branch is also presented. The paper finally provides the conclusion of results and their significance, and accordingly the recommendation of most effective intervention.

2. Methodology

2.1. Study Area

The Nile River is divided into two branches in the Nile Delta namely; Rosetta and Damietta. Rosetta Branch represents the main freshwater stream, which extends from the Delta Barrage at 30° 11' 04.4" N and 31° 07' 00.4" E for about 256 km on the western boundary of the Nile Delta. It ends with Edfina barrage at 31° 18' 22.8" N and 30° 31' 07.9" E with a distance of 30 km upstream the Mediterranean Sea. Rosetta Branch has an average width of 180 m and provides water for agricultural, industrial, domestic, and fishery sectors. The agricultural watershed of study area is served by an intensive drainage network consisting of open and subsurface drains at the farm level, which flow by gravity to secondary drains. There are five main drains namely; El Rahawy, Zaweit El Bahr, El Tahrir, Sabal, and Tala, which collect drainage water from secondary drains and dispose their effluents to Rosetta Branch (Fig. 1). Pollution along the branch mainly originates from these five main drains.

2.2. Data Collection

This study required data for numerical simulation of hydrologic characteristics and water quality along Rosetta Branch. Data from the most recent hydrographic survey conducted by the Nile Research Institute (NRI) at the National Water Research Center in May, 2019 were utilized to represent the geometry of the branch. The hydrographic

Fig. 1. Rosetta Branch and the five agricultural drains.

data covered the length between Delta Barrage at km 26.500 to Edfina Barrage at km 230.00 downstream EL-Roda gage station. The hydrologic data were collected by NRI for the period from 1997 to 2005 containing water levels at eight gage stations as shown in (Fig. 1), and the inflow discharge D.S. Delta barrage. The hydro-topographic maps for the Nile River developed by the Nile Research Institute were also used to obtain the bank level and to fill any missing bathymetric data. Water quality data at various locations in the branch and for the five drains' effluents were also collected.

2.3. Modeling Procedures

Modeling procedures in this research were divided into three stages. The first stage involved the hydrodynamic and water quality simulations along Rosetta Branch under different flow and dredging scenarios using HEC-RAS model. The second stage involved the suggestion of optimal design of CWs for treatment of drains' effluent to Rosetta Branch using SUBWET model. The final stage was to conduct HEC-RAS water quality modeling along the branch with the treated drains by CWs (Fig. 2). The modeling steps were summarized as follows:

- i) Creation and calibration of HEC-RAS model for the hydrodynamic and water quality simulation of Rosetta Branch from Delta Barrage to Edfina Barrage.
- ii) Application of HEC-RAS model for prediction of flows, water surface elevations (WSE), and different water quality parameters along the branch under five dredging scenarios, explained in section 2.3.4.
- iii) Creation and calibration of SUBWET model for simulation of actual CWs at one research station at the Channel Maintenance Research Institute near Delta Barrage.
- iv) Application of SUBWET model to select the optimal designs of CWs for the five drains disposing to Rosetta Branch.
- v) Application of HEC-RAS model to predict the water quality parameters along Rosetta Branch in case of treatment of the five drains.

Fig. 2. Overview flowchart of methodology steps.

2.3.1. HEC-RAS

HEC-RAS model is used for performing many river analysis components such as steady flow water surface profile, 1D or 2D unsteady flow simulation, sediment transport computations and water quality analysis. Water surface profile are computed by solving the energy equation for different sections iteratively with the standard step method. The water quality module within HEC-RAS uses the QUICKEST-ULTIMATE explicit numerical scheme at each water quality cell to solve the 1D advection-dispersion equation. The water quality cells are established between cross sections, and the water quality computational points are located exactly between cross sections pairs. The model simulates the fate and transport of temperature, algae, dissolved oxygen (DO), biological oxygen demand (BOD₅), organic nitrogen (OrgN), ammonium (NH₄), nitrite (NO₂), nitrate (NO₃), and phosphorus (PO₄) using the advection-dispersion.

The current study focused on simulating DO and NH₄ as the most important parameter to recognize the water quality status along Rosetta Branch. DO is the main indicator of organic pollution. Its sources are atmospheric aeration and algal photosynthesis, while its losses are algal respiration, sediment oxygen demand, biological oxygen demand, and oxidation of ammonium and nitrite. DO simulation is based on the following equation:

$$DO = K_2(O_{sat} - DO) + (\alpha_3\mu - \alpha_4\rho) - K_1BOD - \frac{K_4}{d} - \alpha_5\beta_1NH_4 - \alpha_6\beta_2NO_2 \quad (1)$$

O_{sat} = dissolved oxygen concentration at saturation value as a function of water temperature (mg/L)

α_3 = oxygen production per unit algal growth (mg O/mg A)

α_4 = oxygen uptake per unit algal respired (mg O/mg A)

α_5 = oxygen uptake per unit NH₄ oxidized (mg O/mg A)

α_6 = oxygen uptake per unit NO₂ oxidized (mg O/mg A)

K_1 = BOD deoxygenation rate (d⁻¹)

K_2 = reaeration transfer rate (d⁻¹)

K_4 = sediment oxygen demand rate (mg m² d⁻¹)

B_1 = rate of ammonia oxidation (d⁻¹)

B_2 = rate of nitrite oxidation (d⁻¹)

d = average channel depth (m)

Total ammonia (NH₃) is considered an important parameter, since it is toxic to aquatic life at concentrations higher than 0.5 mg/L, and can also cause an excess of algae growth which prevents sunlight from reaching the aquatic life. It is found in water through the decay of organic matter and production of fertilisers, plastics, pharmaceuticals and petrochemicals. The total ammonia was measured as the sum of both un-ionized ammonium (NH₃) and NH₄. Based on pH and temperatures, the total ammonia values were converted to NH₃. Then, the NH₄ values were calculated as the difference between total ammonia and NH₃. In general, NH₄ concentrations are higher with lower pH and higher temperatures due to the increase of H⁺ ions. NH₄, in addition to NO₃, are the main inorganic nitrogen compounds. HEC-RAS can simulate NH₄, where the nitrogen limitation function is mandatory for the simulation process. It is a unit-less function, and is expressed as:

$$FN = \frac{N_e}{N_e + KN} \quad (2)$$

N_e = effective local concentration of available inorganic nitrogen (mg/L) = $\text{NH}_4 + \text{NO}_3$
 KN = half-saturation constant for nitrogen (mg/L)

NH_4 sources are hydrolysis of organic nitrogen and uptake from the benthos, while NH_4 sinks are oxidation of ammonium to form nitrite and algal uptake. Accordingly, the model expresses the NH_4 sources and sinks as following:

$$\text{NH}_4 = \beta_3 \text{OrgN} + \frac{\sigma_3}{d} - \beta_1 (1 - \exp^{-KNR \text{DO}}) \text{NH}_4 - F_1 \alpha_1 \mu \quad (3)$$

β_3 = rate constant for hydrolysis of OrgN to ammonium (d^{-1})
 β_1 = rate constant for oxidation of ammonium (d^{-1})
 σ_3 = benthos source rate (mg N/m² d⁻¹)
 d = average channel depth (m)

μ = local growth rate for algae (d^{-1})
 α_1 = fraction of algal biomass that is nitrogen (mg N/mg A)
 KNR = first order nitrification inhibition coefficient (L/mg)
 F_1 = fraction of algal uptake (unitless), where it is computed as a function of preference factor for ammonia and nitrate (P_N) as following:

$$F_1 = \frac{P_N \text{NH}_4}{P_N \text{NH}_4 + (1 - P_N) \text{NO}_3} \quad (4)$$

For Rosetta Branch, the model was constructed as follows:

- Bathymetric and land data was interpolated together using ArcGIS to create a raster dataset with pixel size 5×5 m.
- The centerline and perpendicular cross-sections along the main stream were created using HEC-GeoRAS tool (Fig. 3(a)).
- The geometry file was exported from ArcGIS and imported

Fig. 3. Model construction for Rosetta Branch. (a) Branch cross sections, (b) Geometry file.

into HEC-RAS software (Fig. 3(b)) to define the boundary conditions for different flow scenarios.

- iv. Different dredging scenarios were applied to the study area as explained in section 2.3.4.
- v. The drains' outlet along the centerline were created.
- vi. The water quality simulation was done by the water quality module within HEC-RAS.

In the current study, 412 hydraulic cross sections were set for Rosetta Branch, resulting in 412 corresponding water quality cells. In addition, another 20 hydraulic cross sections were set for the five agricultural drains. Various pathways between nutrient parameters were presented in a sub-window included in the water quality data file. This sub-window enabled setting rate constants for reactions within specific ranges.

2.3.2. Subwet

The SUBWET model has been developed by UNEP-DTIE-IETC and the Centre for Alternative Wastewater Treatment (CAWT) at Fleming College. The model is used as a predictive tool to determine the size of CWs which can achieve defined removal efficiencies of BOD₅, NO₃, NH₄, OrgN, and PO₄. It is based on an alteration to the aerial loading rates, hydraulic retention time (HRT) and the desired level of effluent treatment. The treatment efficiencies of parameters were expressed in the model according to the following equations:

$$\text{Ammonification} = \text{OrgN} * AC * TA^{(TEMP-20)} \quad (5)$$

$$\text{Nitrification} = \frac{AMM * NC * INOX * TN^{(TEMP-20)}}{AMM + MA} \quad (6)$$

$$\text{Oxidation of organic matter as BOD}_5 = \text{BOD}_5 * OC * INOO * TO^{(TEMP-20)} \quad (7)$$

$$\text{Denitrification} = \frac{NIT * DC * TD^{(TEMP-20)}}{NIT + MN} \quad (8)$$

- OrgN : concentrations of organic nitrogen in inflowing and out-flowing water (mg/L)
- AC : ammonification rate coefficient (L/d)
- TA : temperature coefficient for ammonification (-)
- TEMP : average temperature in centigrade as function of time
- NC : nitrification rate coefficient (L/d)
- INOX : Michaelis-Menten expression for the influence of oxygen on nitrification rate (-)
- TN : temperature coefficient for nitrification (-)
- AMM : ammonium concentrations in inflowing and outflowing water (mg/L)
- MA : Michaelis-Menten constant for nitrification (mg/L)
- OC : oxidation rate coefficient for organic matter, expressed as BOD₅ (L/d)
- INOO : Michaelis-Menten expression for oxygen influence on oxidation rate of BOD₅ (-)
- TO : temperature coefficient for oxidation of BOD₅ (-)
- NIT : nitrate concentrations in inflowing and out flowing water (mg/L)
- DC : denitrification rate coefficient (L/d)
- TD : temperature coefficient for denitrification (-)
- MN : Michaelis-Menten constant for denitrification (mg/L)

The SUBWET model inputs were the assumed dimensions and bed slope, average particular matter, hydraulic conductivity, porosity, influent drainage flow to CW, concentrations of BOD₅, NO₃, NH₄, PO₄ and OrgN, and air temperature. The model parameters were the maximum decomposition rates of OrgN and organic matter, maximum nitrification and denitrification rates, temperature coefficients of ammonification, nitrification, and denitrification, and maximum plant uptake rates of ammonia, nitrate, and phosphorus. The model outputs were the hydraulic loading rate, CW effluent concentrations, and removal efficiencies of BOD₅, NO₃, NH₄, PO₄ and OrgN. For each drain, many designs with different dimensions were tested until the optimal design was selected which achieved the desired treatment efficiencies for various parameters.

2.3.3. Models' calibration

The calibration process was performed firstly for both the hydrodynamic and water quality simulations of HEC-RAS along Rosetta Branch, and then it was performed for the SUBWET model for design of constructed wetlands under Egyptian conditions. The calibration of HEC-RAS hydrodynamic model was done by changing the manning roughness "n" along the modelled reach, then comparing WSE at different gauging stations along Rosetta Branch with simulated results. A flow of 13.10 million m³/d was taken as a calibration flow input as it represented the average flow during the field survey. The calibration of HEC-RAS water quality model was done by changing the ratio of Chla to algae biomass, fraction of algae biomass, oxygen production and uptake per unit of algae growth, growth limitations, organic settling rates, rates for biological oxidations, decay rates, and sediment oxygen demand. Then, the simulated and measured values of DO and NH₄ concentrations were compared at four different locations.

For SUBWET model, the calibration process was undertaken by simulating five actual experimental CWs installed at the Channel Maintenance Research Institute. The location of CWs were at longitude 31° 07' 2400" E and latitude 30° 11' 5100" N in the western bank of the Nile River at Delta Barrages. The CWs had a width of 1 m, length of 4 m, and water depth of 0.7 cm, resulting in a capacity of 2.8 m³. The influent drainage water was transported from Namoul drain in Qualubia governorate. Duckweeds was the main vegetation, which was transported from Eskandar El Mallawia canal in Qualubia governorate. The calibration of SUBWET model was done by changing decomposition rates, coefficients and plant uptake rates. The hydraulic conductivity was chosen in the range from 10⁻⁹ to 10⁻⁶ and the porosity in the range from 33 to 60% as the clay was dominant in the study area according to Fetter [24]. The calibration process for SUBWET model was undertaken by comparing simulated results with field data for BOD₅, NO₃, NH₄, OrgN and PO₄. Eq. (9) presented the Mean Percentage Relative Error (MPRE) (%) between numerical results (N) and field results (F) for testing the performance of both models. There has been no specific range of satisfactory performance for water quality modeling.

In the current study, fulfilling requirements of HECRAS modeling of Rosetta Branch is much more complex than SUBWET modeling of CWs. Therefore, the satisfactory performance of HECRAS model

in the current study could be achieved with MPRE values less than 10 %, while it could be achieved with MPRE values less than 5% for SUBWET model.

$$\text{MPRE} = \frac{\sum \frac{(N-F)}{F} \times 100}{\text{Number of results}} \quad (9)$$

2.3.4. Modelling scenarios

Different scenarios were tested to compare the effectiveness of dredging with treating the drains' effluents on water quality status of Rosetta Branch. For investigation of dredging, five scenarios were proposed with an increment of 40 km from outlet of El Rahawy Drain, as illustrated in Fig. 4(a). The dredging depth was assumed to be 0.50 m beneath the current bed. Hence the geometry was modified for each scenario by lowering the bathymetric data with 0.50 m, while the bank level remained constant. HEC-RAS geometry file for each scenario was created by HEC-GeoRAS.

Fig. 4. Dredging and flow scenarios. (a) Dredging scenarios, (b) Flow scenarios.

The effect of dredging on WSE was tested with minimum, maximum and common flow cases, where the flow values were quantified by analyzing the recorded data of flows D.S. Delta Barrage from 1997 to 2007 as shown in the histogram in Fig. 4(b). The bin interval was 5 million m³/d. The minimum flow was taken at 10% of discharges, which was found at the bin interval from 0 to 5 million m³/d with a value of 4 million m³/d and a corresponding water level U.S. Edfina Barrage of 1.9 m. The maximum value was taken at 90% of discharges corresponding to the bin interval from 25 to million m³/d with a value of 25.25 million m³/d and a corresponding water level U.S. Edfina Barrage of 2.9 m. The common discharge was taken at the bin interval having the highest frequency, which was found from 10 to 15 million m³/d with a value of 13.1 million m³/d and a corresponding water level U.S. Edfina Barrage of 1.9 m as well.

The effect of dredging on water quality was tested for only the fifth scenario for dredging 200 km (Fig. 4(a)). Within the water quality module, all rate constants for reactions were settled with the same values as the current scenario, except the sediment oxygen demand rate which was reduced from 6 g/m² d to zero due to dredging of polluted sediments.

For treating the drains' effluents, SUBWET model was used to provide the optimal design of CWs and to predict the resulting constituents' concentrations into the branch. Only one scenario was tested which assumed the treatment of all the five drains. Then, the current constituents were replaced by the predicted constituents' concentrations within the water quality module of HECRAS model, keeping the sediment oxygen demand with a value of 6 g/m².d.

3. Results and Discussion

3.1. Calibration Results

Fig. 5 shows the simulated and measured water levels along the branch. The calibration results showed a good agreement between measured and simulated values, since both values are almost equal. For calibration of water quality modeling, the concentrations of DO and NH₄ were simulated along the branch and compared with actual field measurements at four locations. MPRE values were 4.45% and 4.82% for DO and NH₄, respectively, indicating confident results (Fig. 6).

For calibrating the SUBWET model for estimating the removal efficiencies of actual CWs at the Delta Barrage, the results were compared with the field measurements. The model indicated confident results with MPRE of 1.52, 2.25 and 1.83 % for BOD, NO₃ and NH₄, respectively.

Fig. 5. HEC-RAS hydrodynamic model calibration.

Fig. 6. Calibration of water quality module within HECRAS for simulation of DO and NH₄ concentrations. (a) DO, (b) NH₄.

3.2. Effect of Dredging on WSE

Maximum, minimum and common flow conditions were applied for both; the current actual case without dredging and with dredging to investigate the effect of dredging. Fig. 7 shows the simulated WSE for different flow cases. It was clear that the backwater effect of Edfina Barrage extended to 108, 90, 103 km from U.S. Edfina Barrage for the maximum, minimum and common flow cases, respectively.

The effect of dredging on changing WSE was evaluated for the five proposed dredging scenarios by calculating the drop in WSE for each scenario. Fig. 7 also illustrates the results of applying different dredging scenarios on WSE for different flow cases. The dredging significantly lowered the WSE along the branch. Results showed that the drop in WSE was by approximately 22 cm at the branch start for all flow cases. The lowering effect differed according to the dredging scenarios. There was no significant change in WSE in the backwater zone except for the maximum flow case.

3.3. Design of Constructed Wetlands by SUBWET Model

SUBWET model provided the optimal design for CWs based on a number of factors namely; site characteristics, inlet water quality parameters, and the desired treatment efficiencies. In order to achieve the desired treatment efficiency, the CW width, length, and depth for El Rahawy drain were 50 m, 85 m, 0.5 m, respectively. The corresponding hydraulic rate was 0.047 m³/m².d. The CW for Talah drain had dimensions of 30 m, 40 m, and 0.5 m with a corresponding hydraulic rate of 0.041 m³/m².d. The CW for Sabal drain had dimensions of 20 m, 40 m, and 0.5 m with a corresponding hydraulic rate of 0.043 m³/m².d. The CW for both Zawiet El Bahr and South Tahrir drains had dimensions of 15 m, 25 m, and 0.5 m with a corresponding hydraulic rate of 0.040 m³/m².d. The resulting treatment efficiencies were integrated with HECRAS model to test the effectiveness of drains' treatment on the water quality

of Rosetta Branch by adding the new concentrations of BOD₅, DO, NO₃, NO₂, NH₄, OrgN, OrgP and PO₄.

3.4. Comparing Bed Dredging with Drains' Rreatment by HEC-RAS Model

The current simulation showed that the DO value along the branch was lower than the standard value (6 mg/L) according to Law 48/1982 and the Ministerial Decree 92/2013 of the Egyptian Ministry of Water Resources and Irrigation for surface water quality criteria (Fig. 6). There was no constant standard value for NH₄ equivalent to values of total ammonia lower than 0.5 mg/L, since the ratio of NH₄ to total ammonia is dependent on the pH and temperature. However, both the simulated and observed NH₄ values were equivalent to total ammonia values higher than 0.5 mg/L along the branch. Both DO and NH₄ values confirmed that the water quality along Rosetta Branch was deteriorated.

In addition, all DO values in the scenario of drains' treatment complied with the DO standard. While, most of DO values in the scenario of bed dredging did not comply with the standard. NH₄ values in the scenario of drains' treatment were much lower than the scenario of bed dredging (Fig. 8). In the current case, the minimum

Fig. 7. Water surface elevation and the drop due to dredging. (a) Without dredging, (b) Dredging-minimum case, (c) Dredging-maximum case, (d) Dredging-common case.

Fig. 8. DO and NH_4 concentrations along Rosetta Branch. (a) DO in case of dredging, (b) DO in case of drains' treatment, (c) NH_4 in case of dredging, (d) NH_4 in case of drains' treatment.

DO concentration along Rosetta Branch was 2.42 mg/L, while the maximum concentration was 6.06 mg/L. In case of bed dredging, the minimum DO concentration increased to 3.62 mg/L, and the maximum concentration increased to 7.55 mg/L. In case of drains' treatment, the minimum concentration had an addition increase to a value of 6.42 mg/L, and the maximum value also increased to 7.91 mg/L. NH_4 values ranged from 0.69 to 2.95 mg/L, 0.55 to 2.72 mg/L, and 0.31 to 0.62 mg/L in the current case, in case of dredging, and drains' treatment, respectively.

4. Discussion

The calibration process shows a satisfactory performance of HECRAS model for hydrodynamic and water quality simulation of Rosetta Branch. SUBWET model also shows a reliability to simulate constructed wetlands under Egyptian conditions in its first application in Egypt. Both models are used in this study to select the most effective intervention for enhancing the water quality along Rosetta Branch. The prevention of drains' disposal is not investigated in the current paper, due to the high significance of their quantities to downstream users. The current results compare treatment of the five main drains flowing into Rosetta Branch and dredging on the hydrodynamics and water quality of Rosetta Branch.

According to the hydrodynamic simulation of Rosetta Branch by HECRAS model, dredging has negative impacts on the WSE, where it drops with a range from 22 cm to 50 cm along the branch. Backwater zone of Edfina Barrage will not significantly change, except for the maximum flow case. The water quality simulation and field measurement shows that the current water quality of Rosetta Branch needs to be improved. Both treatment of agricultural drains and dredging of the branch can raise the DO concentrations and reduce the NH_4 concentrations. The current paper proves that either intervention can enhance the water quality. DO and NH_4 concentrations comply with the water quality standards only in case of drains' treatment, but they do not comply in case of dredging. The current results are in agreement with [22], who used Mike11 model for testing different treatment scenarios, and recommended that reduction of NH_4 concentration in the drains by 70% can improve the current status of the branch water quality.

It is observable that DO concentrations are much higher and NH_4 concentrations are much lower than the case of bed dredging. The current paper finds out that the drains' treatment is much more effective than bed dredging. Based on the negative impact of dredging on hydrodynamics and the low impact on water quality, the current paper recommends the drains treatment.

For providing a clear decision making process, the current paper presents the treatment method which is suitable and implementable under the complex conditions of drainage system consisting of intensive secondary drains ending up with the five main drains. In this regard, CWs are the only effective means for agricultural non-point pollution, and accordingly, they can be applicable at the end of the five main drains to guarantee the treatment of all drainage water. The current paper provides the optimal designs of CWs achieving the desired treatment efficiencies using SUBWET model. The CWs dimensions are 50 m, 85 m, 0.5 m for El Rahawy drain, 30 m, 40 m, and 0.5 m for Talah drain, 20 m, 40 m, and 0.5 m for Sabal drain, and 15 m, 25 m, and 0.5 m for both Zawiet El Bahr and South Tahrir drains.

The current paper clearly proves that drains' treatment by CWs with the selected dimensions will be the most effective and applicable intervention to achieve the desired water quality of Rosetta Branch.

5. Conclusions

- (1) The current paper is the first to specifically provide the

most suitable and effective intervention to enhance the water quality of Rosetta Branch, which its current water quality does not comply with the standards.

(2) Prevention of drains' disposal is not considered, since their huge disposed volumes into the branch are significant in covering the downstream water shortage. Therefore, the current paper is focused on investigating both the drains' treatment and branch dredging.

(3) Based on HECRAS modeling, both interventions can raise the DO concentrations and reduce the NH_4 concentrations. The drains' treatment is much more effective than dredging.

(4) The current paper is the first to investigate the impact of dredging on the hydrodynamics of the branch. Dredging has negative effects on the WSE for the maximum, minimum, and common flows, which also adds a preference to drains' treatment.

(5) From the characteristics of study area, the most proper and applicable treatment method for the five drains is CWs. Based on SUBWET model, the current paper provides the design of each CW achieving the desired treatment efficiency.

(6) The current paper recommends applying CWs for the five drains disposing into Rosetta Branch with the selected designs in order to achieve acceptable water quality in the branch.

Author Contributions

M.M.O. (Associate Professor) conducted the experiments about constructed wetlands and both SUBWET and HEC-RAS modelling, and wrote the manuscript. M.A.G. (Researcher) conducted HEC-RAS modeling, and wrote the manuscript. S.E. (Researcher) conducted HEC-RAS modeling, and wrote the manuscript.

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