Global Warming Impacts on Water Quality in the Nile Delta, Egypt

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Abstract

In this study, a simplified model was calibrated against a relatively more complex model with the objective to achieve simulations with the simplified models. This could only be achieved by implementing the detailed and the simplified model in a complementary way. The simplified model was used to simulate 3 different scenarios to study the effect of the water temperature rise (in the Rosetta branch) on the DO concentrations. The results indicated that Global warming might increase the stress on Rosetta Branch and decline its water quality. Higher water temperatures reduce dissolved oxygen levels, especially for low concentrations (<5 mg/l) which could affect the aquatic life. If this effect was accompanied by flow reduction, deterioration in the quality status of the branch might be severe.

***Key words*:** Rosetta Branch; climate change; water quality; simplified model

1. INTRODUCTION

Global warming is the increase in the average temperature of the Earth's near-surface air and oceans. The Intergovernmental Panel on Climate Change (IPCC) concluded that anthropogenic greenhouse gases are responsible for most of the observed temperature increase since the middle of the twentieth century (IPCC, 2007). On the other hand, natural phenomena such as solar variation and volcanoes produced most of the warming from pre-industrial times to 1950 (Hegerl, et al., 2007; Ammann, et al., 2007).

Increasing global temperature will cause sea levels to rise and will change the amount and pattern of precipitation, probably including expansion of subtropical deserts (Jian, et al.,2007). The continuing retreat of glaciers, permafrost and sea ice is expected, with the Arctic region being particularly affected. Other likely effects shrinkage of the Amazon rainforest and Boreal forests, increases in the intensity of extreme weather events, species extinctions and changes in agricultural yields. Political and public debate continues regarding the appropriate response to global warming (IPCC, 2007). All regions of the world show an overall net negative impact of global warming on water resources and freshwater ecosystems (Arnell, 2006; Alcamo et al., 2007). Areas in which runoff is projected to decline are likely to face a reduction in the value of the services provided by water resources (Dwight et al., 2002). The beneficial impacts of increased annual runoff in other areas are likely to be tempered in some areas by negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality and flood risks (WHO, 2004).

The future effects of climate change on water resources in different parts of the world will depend on trends in both climatic and non-climatic factors. Evaluating these impacts is challenging because water availability, quality and streamflow are sensitive to changes in temperature and precipitation (Abou-Hadid, 2006). Other important factors include increased demand for water caused by population growth, changes in the economy, development of new technologies, changes in watershed characteristics and water management decisions.

The objective of this paper is to study the impact of temperature rise on water quality in the Rosetta Branch in terms of DO. This was decided to be achieved by developing a simplified model and calibrate it against a detailed model (e.g. Mike 11).

Rosetta Branch as a case study

The Nile delta is formed in northern Egypt where the Nile River bifurcates into Damietta Branch (240 km long) and Rosetta Branch (235 km long) and finally drains into the Mediterranean Sea (Figure 1).

Deterioration in water quality of the Damietta and Rosetta branches in the Nile Delta of Egypt occurs in the northward direction due to municipal and industrial effluents disposals and agricultural drainage. Both branches suffer from organic pollution and deficiency of dissolved oxygen. Rosetta branch is more polluted than Damietta branch (El-Sadek et al., 2008). The major sources of pollution of Rosetta branch are El-Rahawy drain which is located at km 9, Sabal drain located at km 70.4, and Tala drain at km 119.3 (considering Delta Barrage is km 0) (Willems et al., 2005).

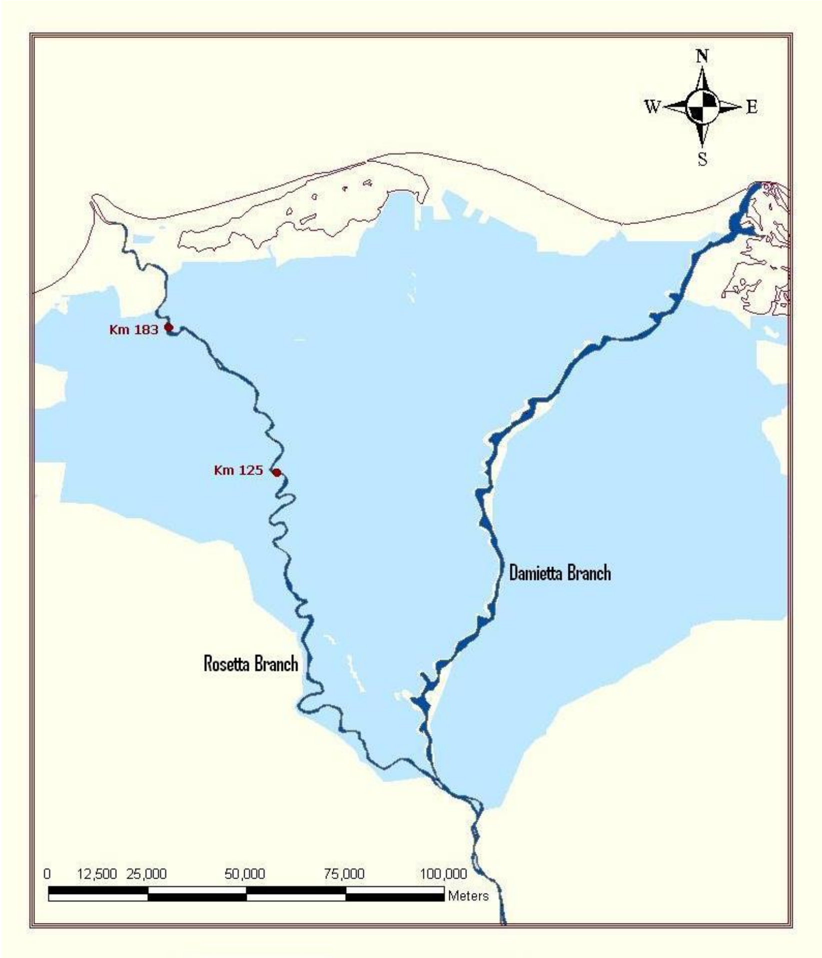

Figure 1: Rosetta and Damietta branches within the Nile Delta

2. METHODS AND MATERIALS

Dissolved Oxygen (DO) dynamics is modelled for Rosetta Branch, Nile Delta using a simplified model calibrated to the detailed Mike 11 model with the objective to yield more easily simulation results without using the Mike 11 license. The construction of the simplified model is however only possible using simulations with the detailed model. Both models thus have to be used in a complementary way. Three different scenarios for the expected rise in water temperature and their effect on the DO concentrations along Rosetta Branch using the simplified model are studied.

2.1. Modelled Parameter: Dissolved Oxygen (DO)

Dissolved oxygen (DO) refers to the concentration of oxygen that is contained in water. Oxygen enters the water by photosynthesis of aquatic biota and by the transfer of oxygen across the air-water interface. The amount of oxygen that can be held by the water depends on the water temperature, salinity, and pressure. Gas solubility increases with decreasing temperature (colder water holds more oxygen). Gas solubility increases with decreasing salinity (freshwater holds more oxygen than does saltwater) (Smith, 1990). Flowing water is more likely to have high dissolved oxygen levels than stagnant water because of the water movement at the air-water interface. Oxygen losses readily occur when water temperatures rise, when plants and animals respire, and when microbes aerobically decompose organic matter.

2.2. Detailed Model

The water quality model considered and implemented in MIKE11 (DHI, 2002) is a coupled model of an advection-dispersion (AD) sub-model and a WQ sub-model. The latter sub-model deals with transforming processes of compounds in the river and the AD sub-model is used to simulate the simultaneous transport process. The WQ sub-model solves the system-coupled differential equations describing the physical, chemical and biological interactions in the river. The river water quality can be dealt with at different levels of detail. In this work, an intermediate detail level has been chosen, including BOD-DO relationships, the exchange with the river bed, nitrification and de-nitrification. Concentrations of dissolved oxygen (DO) are computed.

Processes that affect the oxygen concentration are re-aeration, nitrification, photosynthesis, respiration, oxygen consumption from degradation of dissolved organic matter, oxygen consumption from degradation of suspended organic matter, oxygen consumption from degradation of deposited organic matter, and sediment oxygen demand. The oxygen balance is calculated using the following differential equation which describes the effects of these processes on the dissolved oxygen concentration:

$$\frac{dDO}{dt} = +K_{re-aeration} * (C_S - DO) \quad \text{(re-aeration)}$$

$$-K_{d3} * BOD_d * \theta_{d3}^{(T-20)} \quad \text{(dissolved BOD)}$$

$$-K_{S3} * BOS_S * \theta_{S3}^{(T-20)} \quad \text{(suspended BOD)}$$

$$-K_{b3} * BOD_b * \theta_{b3}^{(T-20)} \quad \text{(deposited BOD)}$$

$$-Y_{nitr} * K_{nitr} * NH_4 - N * \theta_{nitr}^{(T-20)} \quad \text{(nitrification)}$$

$$-R_s * \theta_{resp}^{(T-20)} \quad \text{(respiration)}$$

+ Ph (photosynthesis)

- sd (sediment oxygen demand)……………………………..(1)

where:

Cs : saturation dissolved oxygen concentration, to be calculated by the experimental equation (APHA, 1985):

$$C_s = 14.652 + T\{-0.41022 + T(0.007991 - 0.000077774T)\} \quad \text{[mg/l]}$$

DO	: the concentration of dissolved oxygen	[mg/l]
T	: water temperature	[oC]
Kre-aeration	: the re-aeration rate coefficient at 20°C	[l/day]
Kd3	: the degradation constant for dissolved matter at 20°C	[l/day]
KS3	: the degradation constant for suspended organic matter at 20°C	[l/day]
Kb3	: the degradation constant for deposited organic matter at 20°C	[l/day]
Knitr	: the nitrification rate at 20°C	[mg/l]
BODd	: the actual concentration of dissolved matter at 20°C	[mgO2/l]
BODS	: the actual concentration of suspended organic matter at 20°C	[mgO2/l]
BODb	: the actual amount of deposited organic matter at the bottom	[mgO2/l]
θd3, θS3, θb3	: the Arrhenius temperature coefficients of the degradation process	
Ynitr	: the yield factor describing the amount of oxygen used at nitrification	
NH4-N	: the concentration of ammonia	[mg/l]
θnitr	: the Arrhenius temperature coefficients of the nitrification process	

Rs	: the respiration rate of plants, bacteria and animals	[gO2/m²/day]
sd	: the sediment oxygen demand	
Ph	: the actual production of oxygen	[gO2/m²/day]

$$P = P_{max} \cos 2\pi \left(\frac{\tau}{\alpha} \right) \quad \text{if } \tau \in [\tau up, \tau down]$$

$$P = 0 \quad \text{if } \tau \notin [\tau up, \tau down]$$

Pmax	: maximum production at noon	[g/O2/m²/day]
τ	: actual time of the day related to noon	
α	: actual relative day length	
τup, τdown	: time of sunrise and sunset	

As for the model calibration, it was carried out by comparing the results to the available measurements at the different locations along the Rosetta Branch. The full simulated hourly time series for the period 2000-2003 was compared to the limited number of water quality sampling results during the same period. The locations are: km 125 and km 183.
The results were validated by:

- Longitudinal profiles: variation of the concentration or load versus the distance along the Rosetta Branch
- Scatter plot of the modelled and observed concentrations
- Modelled and observed concentrations or loads versus discharge;
- Difference in load from upstream to downstream along the different reaches (in between locations where water quality measurements are available).

More details of the model calibration and verification are explained in Radwan et al., 2005.

2.3. Conceptual Simplified Model

To evaluate the different water quality processes, a sensitivity analysis was carried out. Based on the results, a simplified river water quality model was set up. In this simplified model, advection and dispersion are modelled using a linear reservoir model. Both parameters are calibrated based on simulations with the Mike 11 model by considering advection-dispersion only. During the residence time of the water in the reservoir, only the most dominant water quality processes are modelled. This is done in a simplified way using “concentration reduction factors”. For calibration of these factors, two simulations were performed with Mike 11. In the first simulation, only the advection-dispersion processes was considered, while in the second simulation the water quality processes was also included. By comparing the results of the first and the second simulation, the concentration reduction factor fDO was derived (Radwan et al., 2003).

3. RESULTS AND DISCUSSION

Results of the sensitivity analysis which were carried out to assess the most sensitive parameters/processes for the purpose of river quality modelling are presented with comparison of the results to the detailed model and measurements. The calibrated simplified model has been used to run different scenarios for the expected rise in water temperature. Three different scenarios were modelled and evaluated.

3.1. Sensitivity Analysis of Water Quality Processes

The aim of the sensitivity analysis is to estimate the rate of change in the output of a model with respect to changes in model inputs. Such knowledge is important for:

- evaluating the applicability of the model
- determining parameters for which it is important to have more accurate values
- understanding the behaviour of the system being modelled.

A sensitivity analysis was carried out for the different water quality processes and parameters to assess the most sensitive parameters/processes for the purpose of river quality management and monitoring plans.

A comparison was held between the simulation results by using default parameter values and a simulation in which the parameter values drastically changed. The change in the simulation results is presented by the concentration reduction factor f which is plotted for all modelled pollutants. Based on the results, the processes which affect the results in a significant way are considered in the conceptual simplified model. The processes examined by the sensitivity analysis are: Nitrification, BOD decay, Photosynthesis, Respiration and Re-aeration. They are derived for the case-study of the Rosetta Branch Nile River at two locations (km 125 and 183).

For the Rosetta Branch, the following simplified river model is derived (using the concentration reduction factor fDO as defined before:

$$f_{DO} = 1 + (\frac{dDO}{dt})T_r \quad \text{.......(2)}$$

Where Tr = residence time

The sensitivity analysis shows that the main processes affecting the DO concentration are the nitrification and the BOD degradation processes. By considering only these processes, the previous equations are written as follows:

$$f_{DO} = 1 - (k_{\deg rad} \frac{BOD}{DO} \theta_{\deg rad}^{T-20} + y_{nitr} k_{nitr} \frac{NH_4 - N}{DO} \theta_{nitr}^{T-20}) T_r \quad \text{.......(3)}$$

3.2. Conceptual Simplified DO Modelling

The Mike 11 model and the conceptual simplified model are simulated for a period of 4 years (January, 2000- December, 2003). The calculations were performed on an hourly basis. The simulation results are presented in figures 2 and 3. From these figures, it could be concluded that the general performance of the two models is satisfactory after a comparison made with the measurements. Moreover, the conceptual simplified model behaves almost similar to the detailed Mike11 model.

Regarding the simulated water quality state, it is concluded that the status of the DO concentrations is much better at km 125 and the situation is deteriorated more downstream at km 183. More specifically, modelled DO concentration violates the recommended standard by law 48/ 1982 during 8% and 55% of the modelled period at km 125 and 183 respectively. The violation of the standards is mainly encountered in as a consequence of the combination of low discharges and pollutant loads.

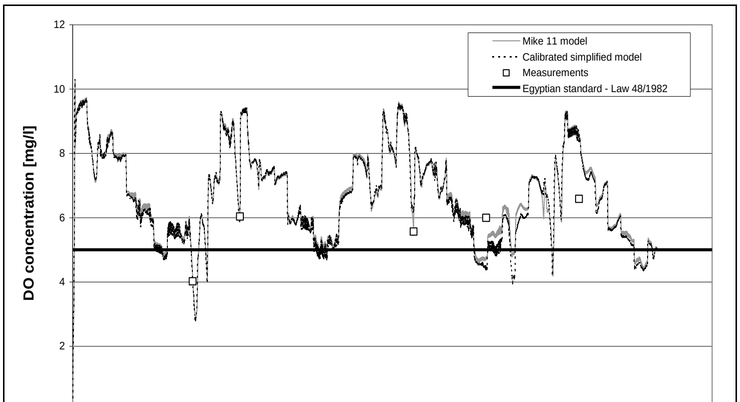

Figure 2: Comparison between detailed Mike 11 and simplified model at km 125

3.3. Scenario Analysis to predict the Effect of the Global Warming on the River Water Quality

The conceptual simplified model calibrated to the detailed Mike 11 model has been used to run different scenarios for the expected rise in water temperature. Three different scenarios were modelled and evaluated.

Scenario 1 presents the current status, scenario 2 presents the rise of the temperature by 1.5 oC and scenario 3 presents the rise of the temperature by 3oC. The values of 1.5 and 3 oC are selected based on the expected changes in the global temperature (IPCC, 2007) with applying a factor for the average reduction between air and water temperature. The average reduction factor is calculated based on a real measured data (NRI, 2000; 2001; 2002a; 2002b; 2003a; 2003b). The results indicated that the average reduction factor has a value of 0.75. Figures 4 and 5 present the results of the three different scenarios at km125 and 183, respectively.

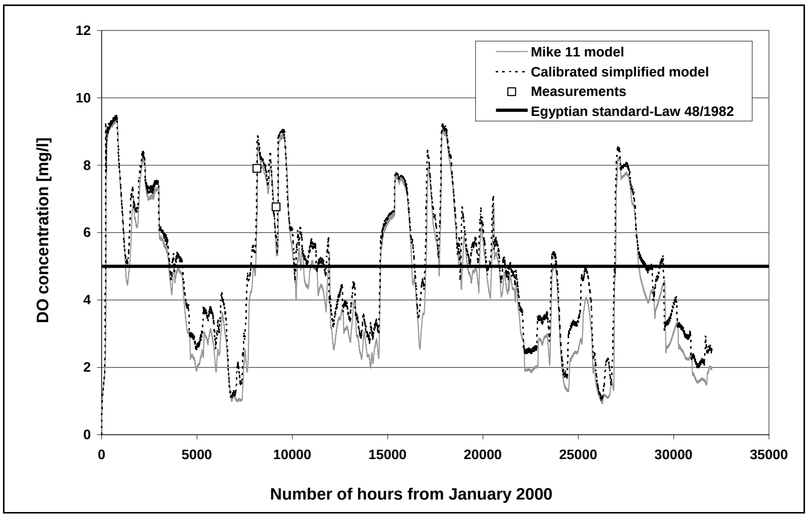

Figure 3: Comparison between detailed Mike 11 and simplified model at km 183

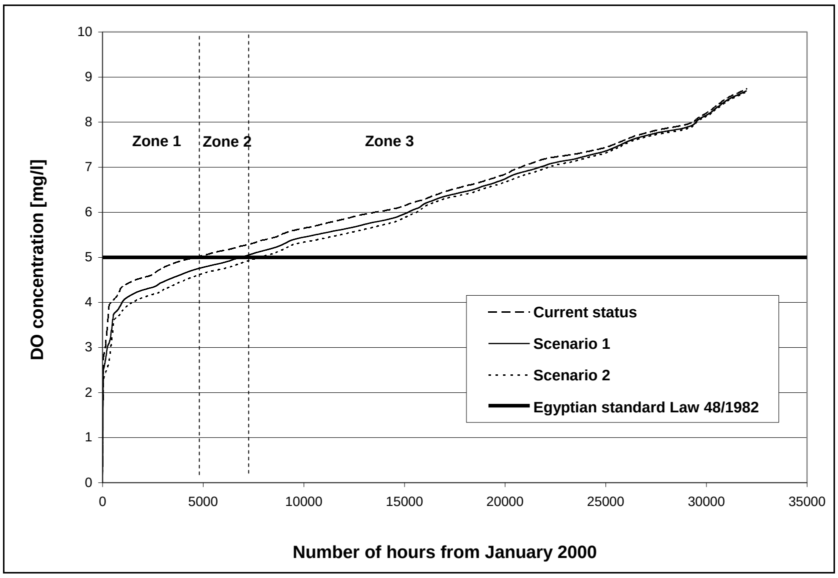

Figure 4: Change in concentration frequency distribution and comparison with the Egyptian standard (Law 48/1982) at km 125.

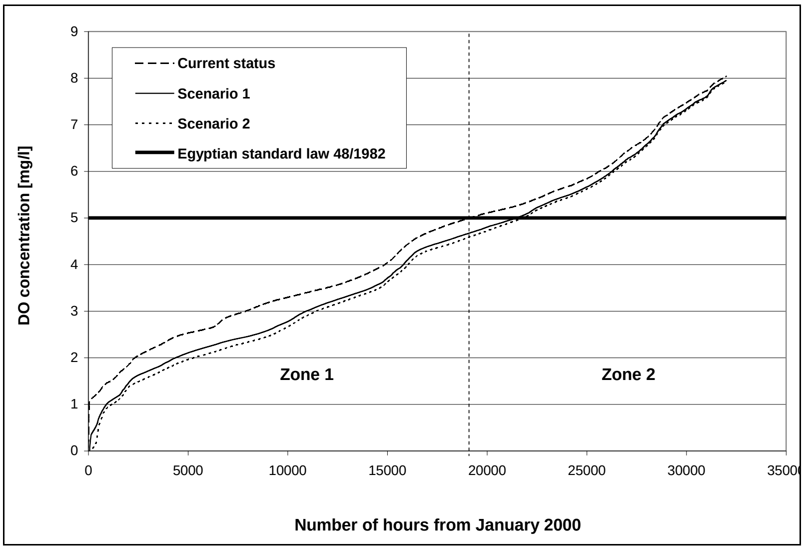

Figure 5: Change in concentration frequency distribution and comparison with the Egyptian standard (Law 48/1982) at km 183.

From figure 4, the results can be divided into three zones (zone1, zone 2 and zone 3). For zone 1, current status, scenario 1 and scenario 2, modelled concentrations are lower than (violating) the recommended standard. For zone 2, current status for DO is within the recommended standard while for the two modelled scenarios, 55% and 78% of the modelled concentrations violate the recommended standard for scenario 1 and scenario 2 respectively. Both current status and predicted DO concentrations fulfill the standard in zone 3. At km 125 (figure 4), the average reduction for predicted DO concentration for scenario 1 is 7%, 5% and 2% for zone 1, zone 2 and zone 3, respectively. For scenario 2, the average concentration reduction is 11%, 7% and 3%, respectively. At km 183 (figure 5), the average reduction for predicted DO concentration for scenario 1 is, 16%, and 3% for zone 1 and zone 2 respectively. For scenario 2, the average concentration reduction is 21% and 3.5% respectively. Summary of the results for the two modelled scenarios are presented in table 1.

Table 1 Percentage of DO concentration reduction for modelled scenarios compared to current status

	% of DO concentration reduction				
	Km 125			Km 183	
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2
Scenario 1	7	5	2	16	3
Scenario 2	11	7	3	21	3.5

4. CONCLUSION

- In this study, a conceptual simplified model has been calibrated to a detailed physico-chemical water quality model (MIKE11) for the Rosetta Branch in the Nile Delta.
- The WQ model aims to describe and predict concentrations of dissolved oxygen (DO), taking into consideration advection, dispersion and the most important biological, chemical and physical processes.
- In fact, Rosetta branch suffers from organic pollution and deficiency of dissolved oxygen. All significant pollution sources along the Rosetta Branch were considered.
- The objective of this study was to use the simplified model to study the effect of predicted global warming in terms of expected temperature rise on the water quality status in terms of DO for Rosetta branch in the Nile Delta of Egypt.
- The results indicated that global warming is likely to increase the stress on Rosetta branch and to decrease its water quality. Higher water temperatures reduce dissolved oxygen levels, especially for low concentrations (<5 mg/l) which can have a negative effect on aquatic life. If this effect will

be combined with reduction in streamflow, the deterioration of the quality status of the branch might be severe.

- As the highest expected DO concentration reduction is recorded for low concentrations (<5mg/l) which indicate water quality deterioration. That could have implications for all types of uses. Prolonged exposure to low dissolved oxygen levels (<5 mg/l) may not directly kill an organism, but will increase its susceptibility to other environmental stresses. Exposure to<30% saturation (<2 mg/l oxygen) for one to four days may kill most of the biota in a system (Gower, 1980). Finally, higher temperatures and changes in water supply and quality could affect recreational use of rivers or productivity of freshwater fisheries and aquatic life (Smith, 1990).

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