CLIMATE CHANGE IMPACTS ON WATER QUALITY INDICES OF THE SOUTHERN PART OF ASWAN HIGH DAM RESERVOIR, LAKE NUBIA

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ABSTRACT

Egypt is one of the most vulnerable countries to the potential impacts and risks of climate change. More than 95 % of the water budget of Egypt is received from the River Nile, which is very sensitive to temperature and precipitation changes. Aswan High Dam (AHD) reservoir, one of the largest man-made lakes in the world, is almost the sole source of freshwater to the country; hence, Egypt realized the importance of protecting the reservoir from pollution.

The global climate change effect on two water quality indices (WQIs) of Lake Nubia, the National Sanitation Foundation (NSF-WQI) and the Canadian Council of Ministers of the Environment (CCME-WQI), was investigated in this study. The investigation was conducted for the 21st Century by using the outputs of eleven global climate models (GCMs) for two global emissions scenarios combined with hydrological modeling. To estimate the water quality indices of Lake Nubia in the future, a model was presented using a two-dimensional, laterally averaged, finite difference hydrodynamic and water quality code, CE-QUAL-W2. The model was calibrated and verified with measured data series from the years 2006 and 2007, respectively. The results show that future climate change will slightly affect the investigated indices.

Keywords: Climate change, Water quality index, Aswan High Dam reservoir

1. INTRODUCTION

Since last century, climate change has been accelerated due to the increase in greenhouse gases related to human activities (CECC [1]). The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to assess the environmental and socioeconomic implications of climate change and the possible response options available to governments. IPCC has released four assessment reports in 1990, 1995, 2001 and 2007. The latest IPCC Assessment Report (IPCC [2-4]) stated that Earth’s average temperature is unequivocally warming, 11 of the past 12 years have been the warmest on record since 1850, which is when global instrumental record-keeping began.

Developing countries, such as Egypt, are the most threatened ones by the hydrological impacts of global climate change (Svendsen and Künkel [5]). The first and second Egyptian communications reports (EEAA [6-7]), which were prepared by the Egyptian Environmental Affairs Agency (EEAA) to submit to the United Nations Framework Convention on Climate Change (UNFCCC), reported that Egypt is one of the most vulnerable countries to the potential impacts and risks of climate change, even though it produces less than 1 % of the world total emissions of greenhouse gases. More than 95 % of the water budget of Egypt is received from the River Nile which is generated outside Egypt's territory. Numerous studies showed that River Nile is very sensitive to temperature and precipitation changes (Riebsame et al. [8]). Aswan High Dam (AHD) reservoir was formed as a result of the construction of AHD at Aswan, Egypt, to control the River Nile. Egypt realized the importance of protecting the reservoir from pollution, as it is almost the sole source of freshwater to the country.

Water quality state of a water body depends on a large number of physical, chemical and biological indicators. An evaluation approach, such as water quality index that can be used to indicate the overall water quality condition, is essential. Mainly there are four main approaches that can be used to assess the water quality of a water body: (1) water quality index approach, (2) trophic status index approach, (3) statistical analysis approaches of the water quality data such as correlation analysis and (4) biological analysis approaches such as Genetic Algorithms method and other different biological indices.

A water quality index (WQI) can be defined as any mathematical approach which aggregates data on two or more water quality variables to produce a single number (Ott [9]). It consists of water quality variables such as dissolved oxygen, total phosphorus and fecal coliform, each of which has specific impacts to beneficial uses. Water quality index concept was first introduced more than 150 years ago, in 1848, in Germany where presence or absence of certain organisms in water was used as an indicator of the fitness or otherwise of a water source (Abbasi [10]). There are several water quality indices that have been developed to assess water bodies. In 1965, the first-ever modern WQI was developed and published by Horton (Horton [11]). Since 1965, many different water quality indices have been addressed in the literature (Brown et al.[12], CCME [13], Said et al. [14], Sarkar and Abbasi [15], Smith [16], and Steinhart et al. [17]). Two of the best known water quality indices, which have been frequently used, are the National Sanitation Foundation Water Quality Index (NSF-WQI) and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI). These two indices were chosen for this study.

In the framework of this study, the global climate change effect on two of water quality indices for the southern part of the AHD reservoir, Lake Nubia, has been investigated for the 21st century.

2. STUDY AREA AND METHODOLOGY

2.1 Site Characterization

AHD reservoir, one of the largest man-made lakes in the world, was formed as a result of the construction of AHD. The reservoir extending about 500 km upstream from the Aswan High Dam between the latitudes 23° 58' and 20° 27' N, and between longitudes 30° 35' and 33° 15' E (Figure 1). The current length of the submerged area is about 500 km, of which 350 km are within the Egyptian territory and is known as Lake Nasser. The 150 km stretch which lies in the northern part of Sudan is known as Lake Nubia. Lake Nubia is the investigated area of this work.

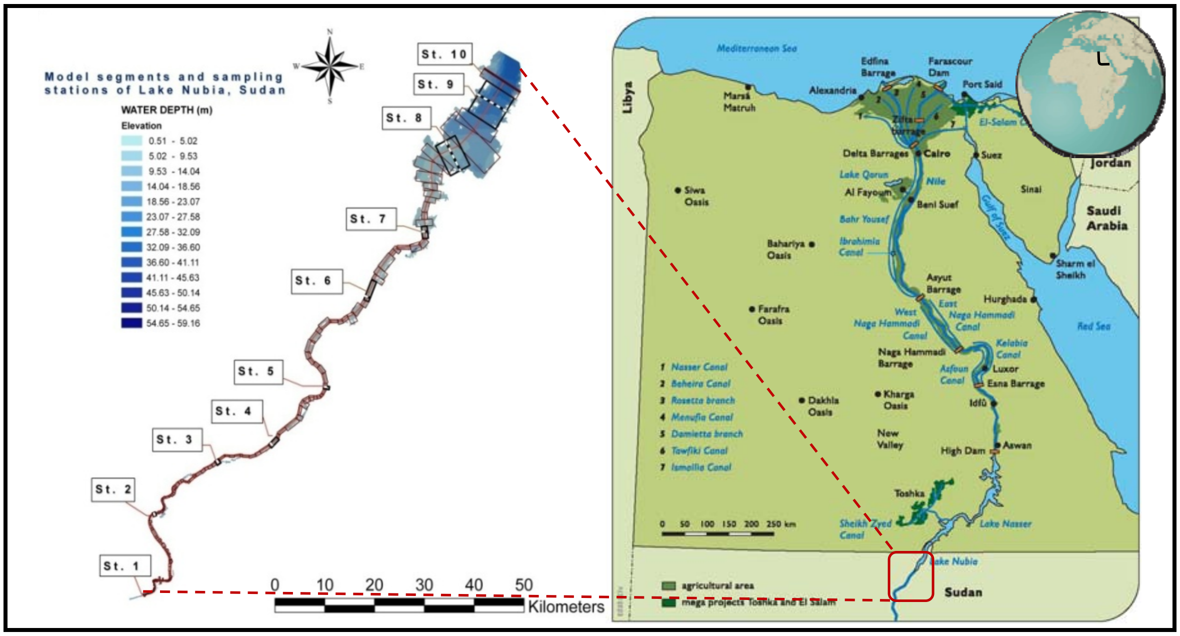

Figure 1: Location map of Lake Nubia (MWRI [18]), Lake Nubia bathymetry (plan view), January 2006, and sampling stations.

The reservoir has a maximum water depth of 130 meters (the mean depth is about 25 meters), or 182 meters above mean sea level (AMSL), and a total capacity of 162 BCM (about 15% of that for Lake Nubia). At this water level, the reservoir have an average width of 12 kilometers and a surface water area of 6540 km^2, Lake Nubia has about 14.8% of the total surface area of the reservoir. Figure 2 shows the topography of the reservoir region.

The River Nile is the main and sole inflow source of Lake Nubia. Lake Nubia can be divided into two sections: the riverine section and the semi-riverine section (Abdel-Latif [19]). The riverine section, with all-year riverine characteristics, comprising the southern part of the lake, from the southern end to Daweishat, station No. 5 (St. 5), as shown in Figure 1. The semi-riverine section, with riverine characteristics during the flood season (from the second half of July to November) and lacustrine characteristics during the rest of the year, covers the northern part of the lake extending from

Daweishat. The study area is situated in a desert area, the climate is extremely arid. The rainfall of this area is extremely irregular and variable.

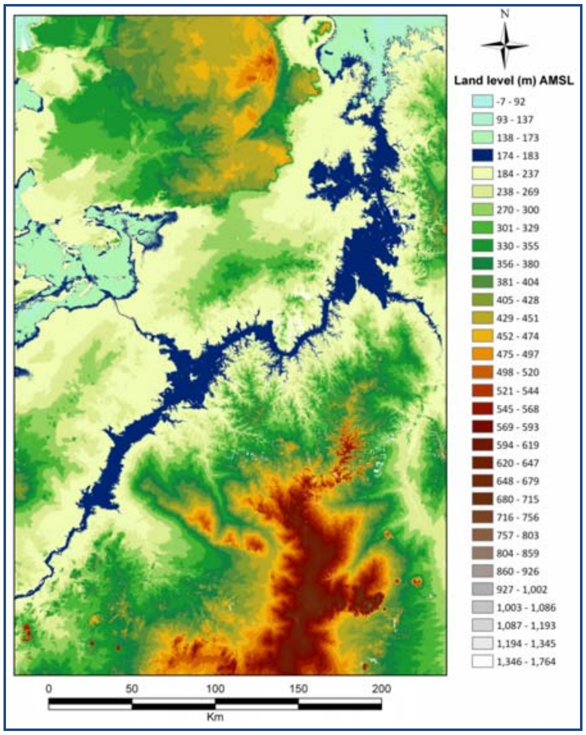

Figure 2: AHD reservoir region topography.

Generally, from samples collected before and after the flood, the reservoir water has good physical and chemical characteristics for using (Saad [20]). The thermal pattern of the reservoir is warm monomictic; the reservoir stratifies in summer and mixing occurs in winter (Williams [21]). Transparency is affected by the turbidity caused by silt and clay of riverine origin; it is particularly strong in the flood season.

2.2 Approach

In order to investigate the impact of future climate change on two water quality indices (NSF-WQI and CCME-WQI) of Lake Nubia, a developed hydrodynamic and water quality model for Lake Nubia and projected changes in climate conditions are required. A hydrodynamic and water quality model of Lake Nubia was developed by Elshemy et al. [22], refer to the next section (2.3) for more details. While the projected climate conditions have been obtained from the study of Beyene et al. [23], refer to section 2.5. Another study has been done by Elshemy et al. [24] for developing NSF-WQI and CCME-WQI to evaluate the water quality of Lake Nubia, during low flood period, January 2006 (refer to section 2.4). Moreover, the results of two different studies, which investigate climate change impacts on the hydrodynamic and water quality characteristics of Lake Nubia, are also used, section 2.6 (Elshemy and Meon [25-26]). Figure 3 summarizes the applied approach.

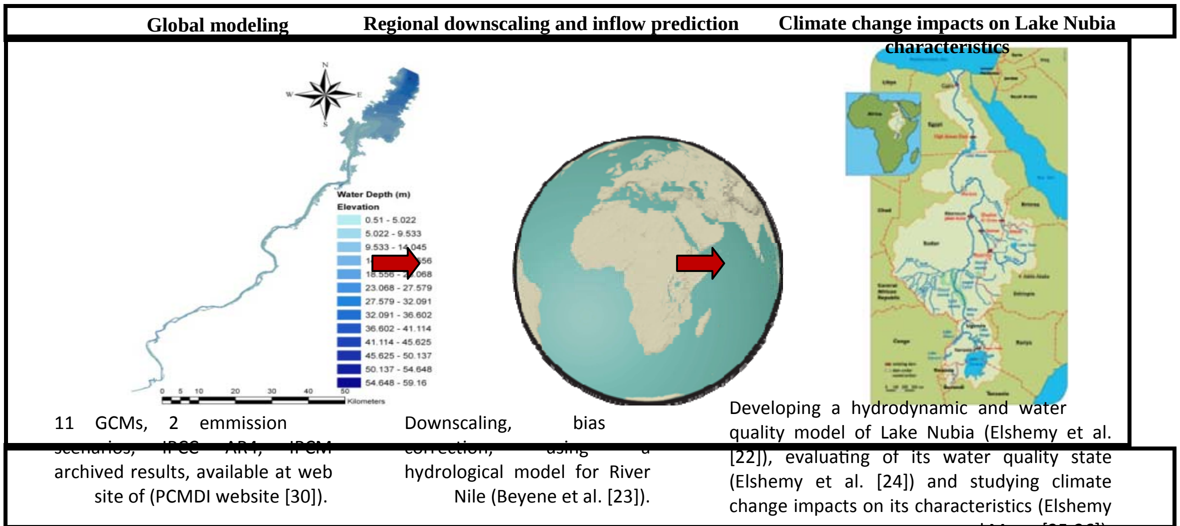

Figure 3: Approach for analyzing potential impacts of climate change on Lake Nubia characteristics.

2.3 Lake Nubia Hydrodynamic and Water Quality Model

Elshemy et al. [22] have developed a two-dimensional (laterally averaged) hydrodynamic and water quality model for Lake Nubia. The developed model was based on a two-dimensional hydrodynamic and water quality modeling system (code), CE-QUAL-W2. This code contains one module, which models both hydrodynamics and water quality. The model can compute water surface elevation, horizontal and vertical velocities, evaporation water losses, water temperature and twenty-eight other water quality parameters (Cole and Wells [27]). The basic input data for CE-QUAL-W2 include: reservoir topography (bathymetry), stream flow, temperature, water quality records as well as meteorological information. The bathymetry of Lake Nubia was modeled by establishing a finite difference grid, using a GIS tool, consisting of three main branches with 202 segments along a longitudinal axis and 27 vertical layers of 2 m depth, as seen in Figures 2 and 5. A specific width was assigned to each cell of the model grid. The inflow data are supplied from a gauging station at the upstream end of the reservoir, St. 1, as shown in Figure 1. All inflows and reservoir surface elevations were specified as daily average values. The meteorological data were obtained for the nearby local meteorological station from the internet (website of “Weather Underground” [28]). The recorded data were given for every six hours. In-reservoir temperature profiles were measured at 10 stations (St. 1-10) positioned along the longitudinal axis of Lake Nubia, as seen in Figure 1. The water samples were collected from the surface and at 25, 50, 65 and 80% depth. The field data in January 2006 and in February 2007 were used to calibrate and verify the model, respectively. Two statistical parameters were used to compare simulated and measured in-reservoir observations, the absolute mean error (AME) and the root mean square error (RMS) (Cole and Tillman [29]).

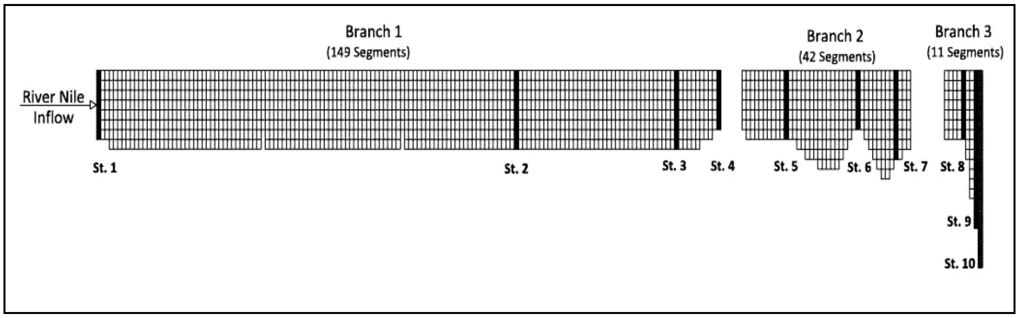

Figure 4: Lake Nubia model bathymetry January 2006, longitudinal section view.

The calibrated and verified hydrodynamic model simulation shows a good agreement with the observed water surface levels and the measured water temperature profiles at various locations and dates, as can be seen in Figures 5 and 6 (as examples).

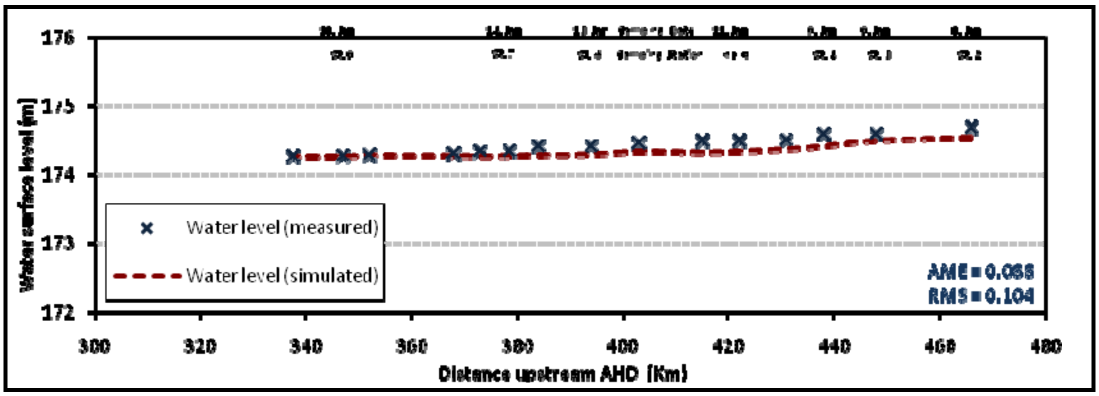

Figure 5: Longitudinal profile of water surface levels in Lake Nubia at different stations and dates, January 2006.

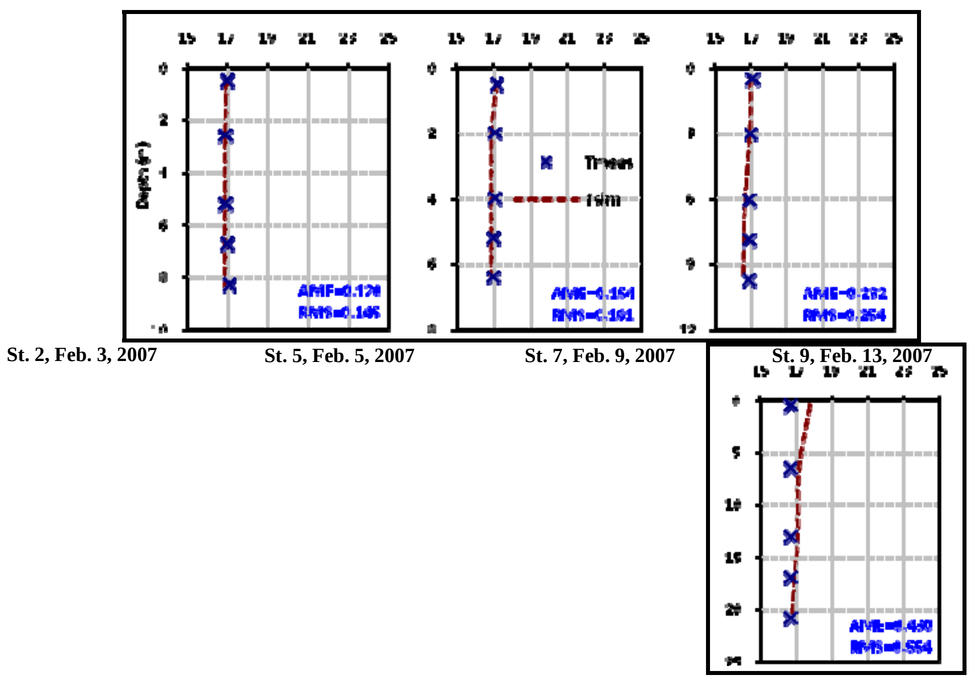

Figure 6: Model verification: vertical profiles of water temperature (°C) in Lake Nubia at different stations and dates, February 2007.

The water quality model reproduces spatial and temporal concentration distributions of key water quality constituents such as: dissolved oxygen, chlorophyll-a, ortho-phosphate, nitrate-nitrite, ammonium, total dissolved solids, total suspended solids, and pH. The model results closely mimic the measured vertical profiles of the water quality constituents, as can be shown in Figure 7 (as an example).

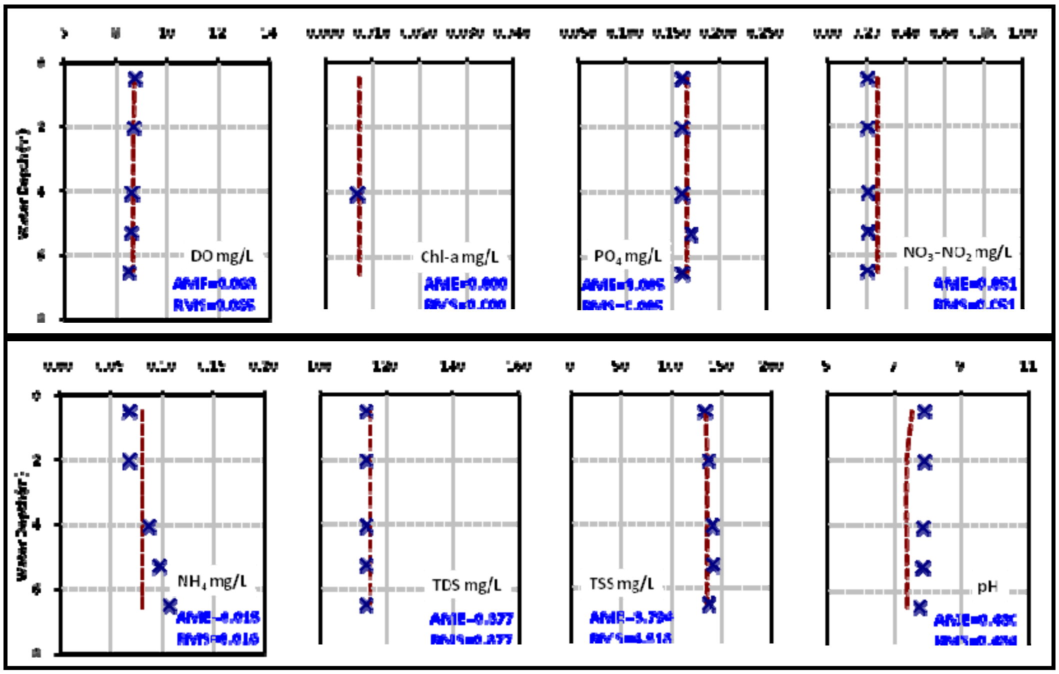

Figure 7: Model calibration: vertical profiles of measured (x) and simulated (---) key water quality parameters in Lake Nubia at St. 2 on 8. January 2006.

2.4 Lake Nubia Water Quality Indices

Two water quality indices were developed to evaluate the water quality state of Lake Nubia during low flood period, January 2006, by Elshemy et al. [24]. These indices were NSF-WQI and CCME-WQI. The measured data were collected during low flood period, January 2006, from ten control stations along Lake Nubia at different water depths. A comparative study has been done to the measured data by using the results of the developed Lake Nubia hydrodynamic and water quality model (section 2.3).

2.4.1 NSF-WQI

Eight parameters were used to apply NSF-WQI to Lake Nubia: dissolved oxygen (% sat), fecal coliform (colonies/100 ml), pH (standard unit), temperature change (degrees C), total phosphate (mg/L), nitrate (mg/L), turbidity (NTU) and total solids (mg/L). Figure 8 shows the longitudinal profiles of the developed NSF-WQI along Lake Nubia at different stations for measured and simulated water quality parameters. While the average NSF-WQI of Lake Nubia for measured and simulated water quality parameters are shown in Figure 9.

2.4.2 CCME-WQI

CCME-WQI was developed to estimate the overall water quality status of Lake Nubia. Seven water quality parameters, measured and simulated (January, 2006), were used. These parameters are: Dissolved oxygen (mg/L), total dissolved solids (mg/L), nitrate-nitrite (mg/L), ammonium (mg/L), total phosphorus (mg/L), fecal coliform (colonies/100 ml) and pH (standard unit). CCME-WQI has been developed according to the Egyptian drinking water quality standards (objectives), Law 48/1982 – Article No. 60 (EEAA [30]), Table 1. For fecal coliform, as there exists no Egyptian standard for it, the used objective was previously used by Heikal et al. [31]. Figure 10 shows the overall CCME-WQI of Lake Nubia for measured and simulated water quality parameters, January 2006.

Table 1: Egyptian drinking water quality standards (objectives).

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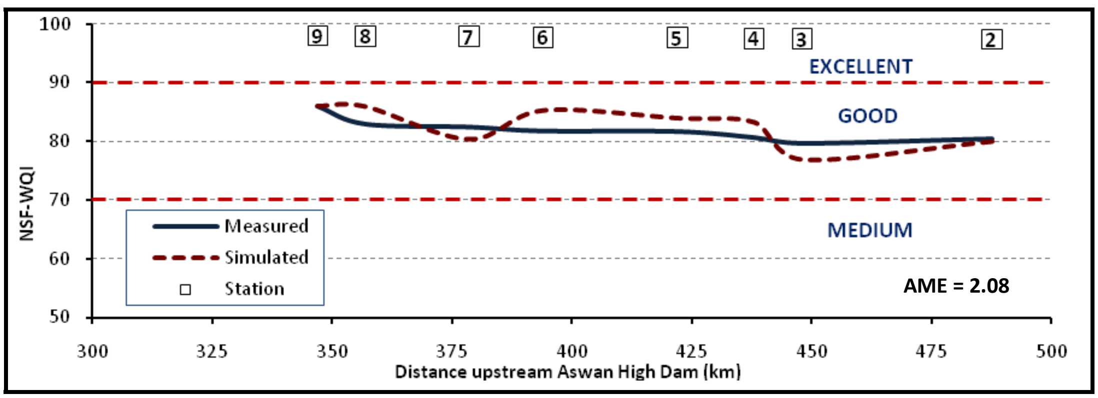


Figure 8: Lake Nubia NSF-WQI longitudinal profiles at different stations for measured and simulated water quality parameters, January 2006.

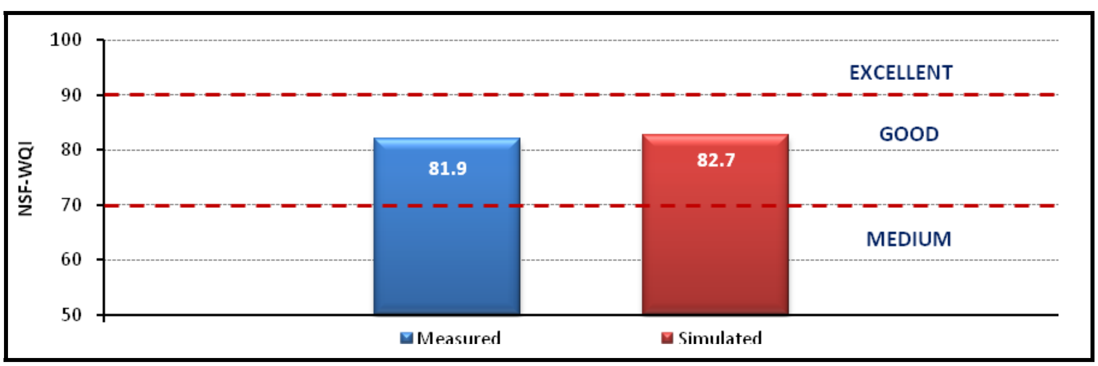


Figure 9: Lake Nubia average NSF-WQI for measured and simulated water quality parameters, January 2006.

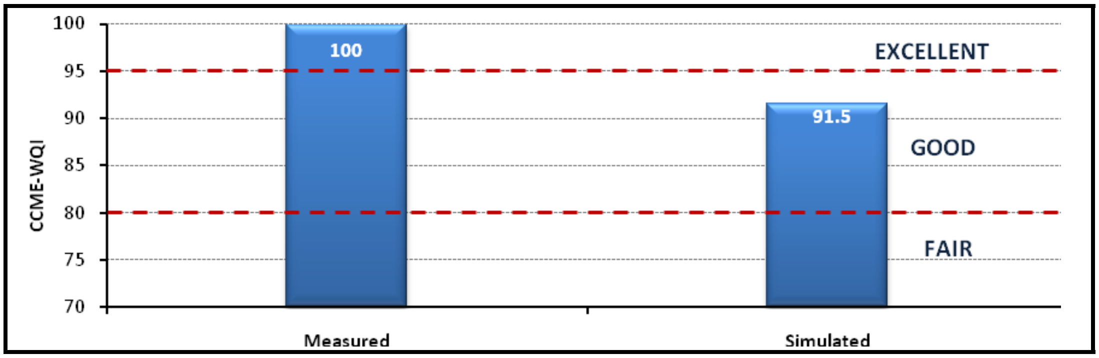


Figure 10: Lake Nubia CCME-WQI for measured and simulated water quality parameters, January 2006.

2.5 Lake Nubia Climate Change Estimates

Future climate change estimates for Lake Nubia have been investigated by Beyene et al. [23]. They assessed the potential impacts of climate change on the hydrology of the River Nile basin for three periods in the 21st Century; period I (2010-2039), period II (2040-2069) and period III (2070-2099). They used the results of eleven global climate models (GCMs) and two global emissions scenarios (A2 and B1), archived from the 2007 IPCC Fourth Assessment Report (AR4), available at web site of PCMDI website [30]. The archived results were bias corrected and spatially and temporally downscaled, by disaggregating the values of temperature and precipitation at the GCM spatial scale in space (to the 1/2° latitude–longitude resolution) and in time (from monthly to daily). These results were used for developing a macro-scale hydrological model to simulate the river inflow. The bias corrected air temperature changes, precipitation changes, and simulated main Nile stream flow changes for some scenarios are represented in Figures 12 and 13.

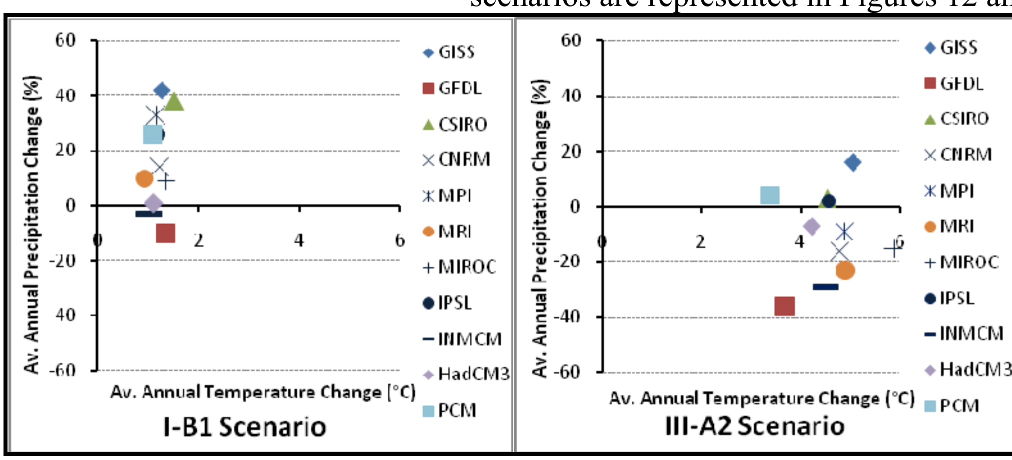


Figure 11: Annual average change for the study area in temperature (°C) and precipitation (%) relative to 1950-1999 historical average for each GCM and two selected scenarios.

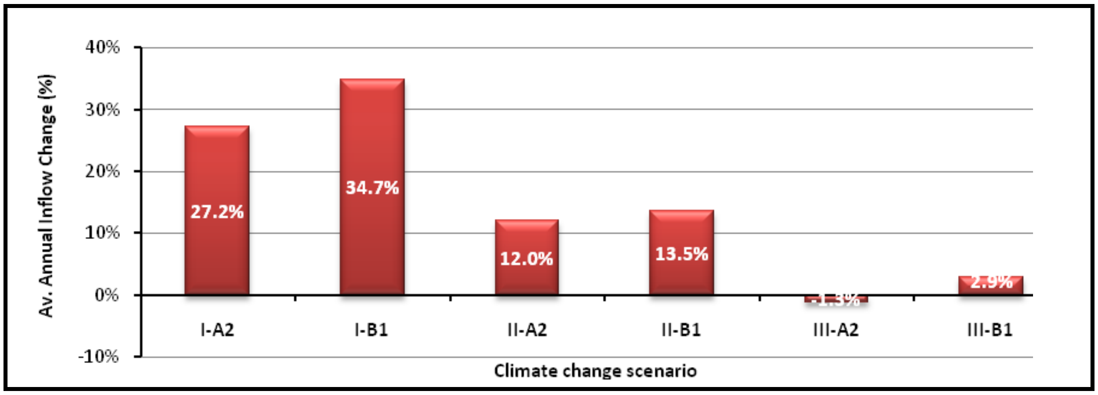


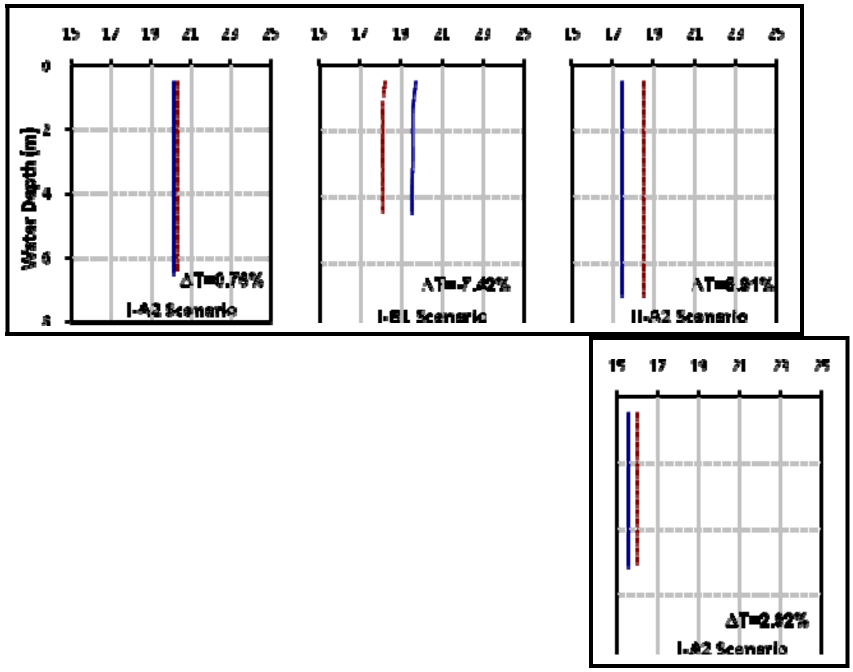
Figure 12: Annual multi-model average change (%) for the study area in the inflow, relative to 2006 base case average for all scenarios.

2.6 Climate Change Impacts on the Hydrodynamic and Water Quality Characteristics of Lake Nubia

The effect of the global climate change on the hydrodynamic and water quality characteristics of Lake Nubia was conducted for the 21st Century (Elshemy and Meon [25-26]). The estimated climate changes, the former section (2.5), were used. A theoretical process algorithm has been simplified, further developed and calibrated to modify the future initial conditions of dissolved oxygen. A sensitivity analysis has been conducted by using each of the predicted air temperature and inflow separately in order to investigate its effect on the characteristics of the hydrodynamic and water quality.

The investigated hydrodynamic characteristics were: water surface levels, evaporation water losses and reservoir thermal structure. While for water quality study, eight water quality parameters of the reservoir were studied with respect to climate change: dissolved oxygen, chlorophyll-a, ortho-phosphate, nitrate-nitrite, ammonium, total dissolved solids, total suspended solids and pH. The results of the climate change study show significant impacts on the examined hydrodynamic and water quality characteristics.

Figure 13 presents Lake Nubia water temperature profiles for some selected scenarios and stations. While Figure 14, as an example, shows Lake Nubia water quality characteristics profiles due to global climate change for II-B1 scenario at St. 4. ΔT and ΔC are the average changes (%) between the simulated base case of the year 2006 and the simulated scenario case.



St. 2 St. 5 St. 7 St. 8

Figure 13: Lake Nubia water temperature profiles (°C) due to global climate change [- - -] for some selected scenarios and stations, compared with the simulated base case [—].

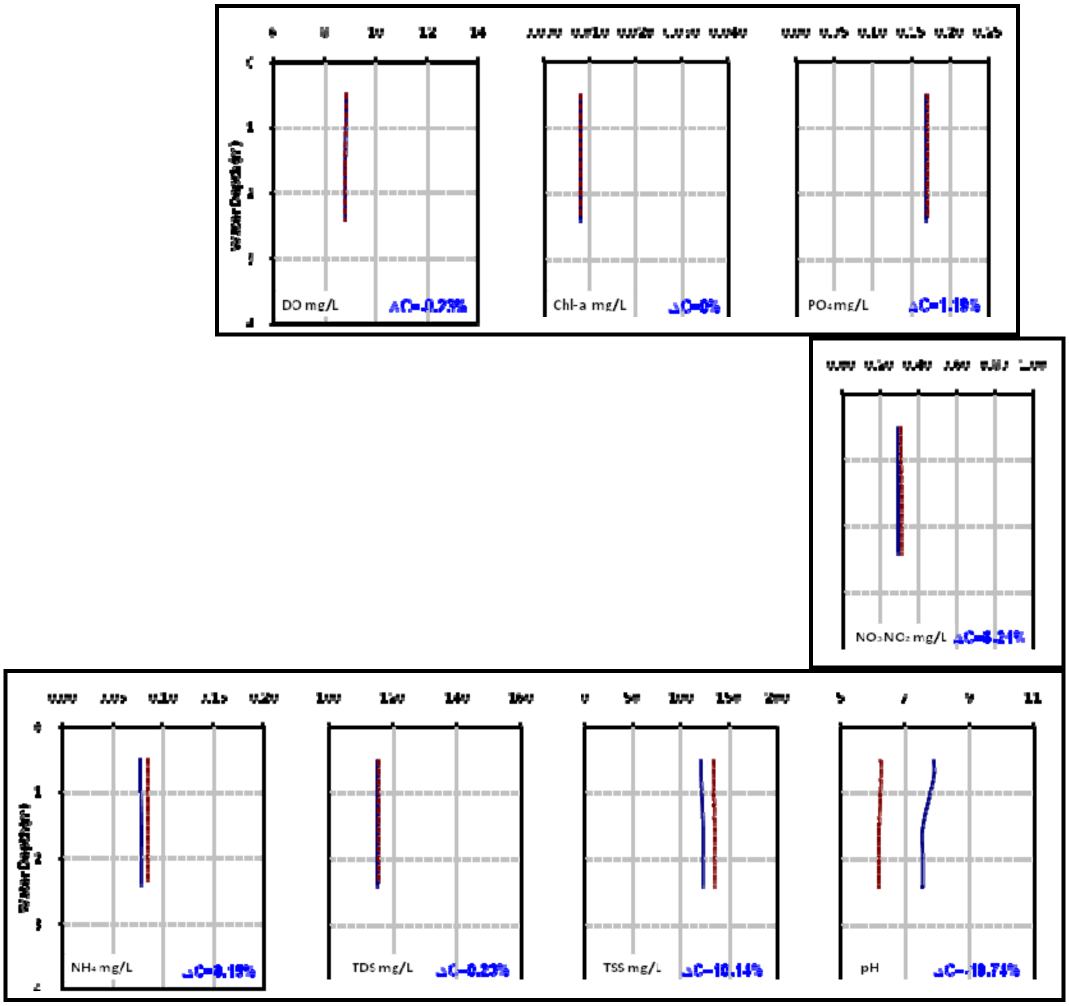


Figure 14: Lake Nubia water quality characteristics profiles due to global climate change [- - -] for II-B1 scenario at St. 4, compared with the simulated base case [—].

3. RESULTS AND DISCUSSION

The main goal of this study is to roughly quantify the potential impact of the global climate change on two water quality indices, NSF-WQI and CCME-WQI, of Lake Nubia. In doing so, we recognize the limitations of this modeling approach including the uncertainty in GCMs output, the hydrological model and the hydrodynamic and water quality model. Thus, the results presented here are an indication of the effects of climate change on NSF-WQI and CCME-WQI of Lake Nubia, and are not intended to be exact predictions. The effect of global climate change on both water quality indices NSF and CCME has been investigated and presented relative to the calibrated model results of the 2006 base case.

3.1 Climate Change Impacts on Lake Nubia NSF-WQI

Figure 15 shows the effect of climate change on the average NSF-WQI of Lake Nubia. The change of average NSF WQI due to climate change is controlled by the change of inflow more than the change of air temperature; where the inflow change affect most of the water quality used parameters. The climate change will slightly decrease the average NSF-WQI of Lake Nubia; the lowest decrease will be 3%, relative to the base case, for scenario I-B1 which will have the maximum predicted inflow change (+34.7%). Average NSF-WQI change for scenario III-A2, which will have the maximum predicted air temperature change (3.9 °C) and the minimum predicted inflow change (-1.3%), will be -0.6%, relative to the base case.

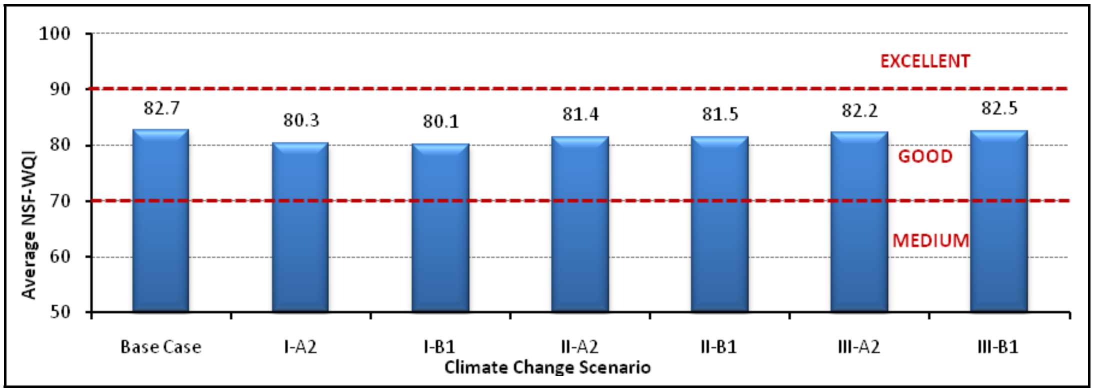


Figure 15: Lake Nubia average NSF-WQI for different climate change scenarios.

Figure 16 presents the longitudinal profiles of Lake Nubia for I-B1 and III-A2 climate change scenarios which reflect the maximum and minimum predicted flow scenarios, respectively. For I-B1 scenario, the maximum NSF WQI change will be -6.2 % at St. 4 because of the increase of suspended solids and fecal coliform concentrations and the decrease of pH due to the increase of inflow by 34.7 %. While, for the low predicted inflow III-A2, the maximum NSF-WQI change will be -2.4 % at St. 6 because of the water temperature and pH increase and DO decrease.

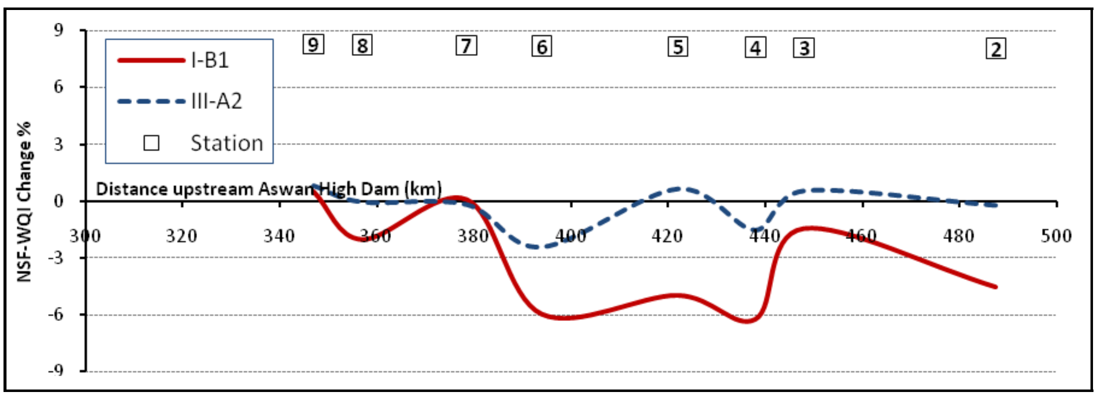


Figure 16: Lake Nubia average NSF-WQI longitudinal profiles for some selected climate change scenarios.

3.2 Climate Change Impacts on Lake Nubia CCME-WQI

The effect of climate change on the CCME-WQI of Lake Nubia for different climate change scenarios can be seen in Figure 17. Climate change will slightly decrease CCME-WQI of Lake Nubia; the highest decrease will be 2.7% at I-B1 scenario, where the predicted inflow is the maximum change (+34.7%). While the lowest decrease will be 0.3% at III-A2 scenario, where the predicted inflow change is the minimum (-1.3%) and the predicted air temperature change is the maximum (3.9 °C).

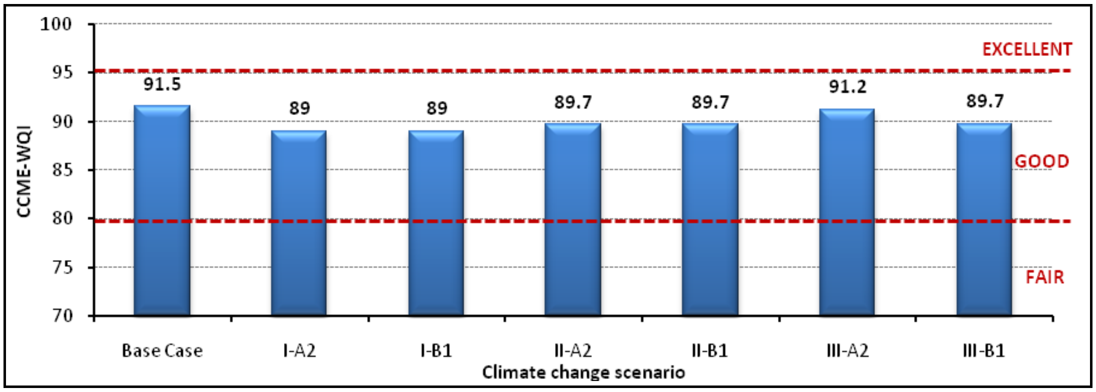


Figure 17: Lake Nubia CCME-WQI for different climate change scenarios.

4. CONCLUSIONS

The impacts of climate change on two water quality indices, NSF-WQI and CCME-WQI, of Lake Nubia have been investigated using a proposed hydrodynamic and water quality model, which simulates three periods: I [2010-2039], II [2040-2069] and III [2070-2099] - with two emission scenarios, A2 and B1, for each period, including the average of eleven GCMs outputs. The global climate change effects are presented relative to the calibrated model results of the year 2006 base case.

The effect of global climate change on both water quality indices NSF and CCME has been investigated. The results show that future climate change will slightly affect the investigated indices. From the presented results it can be concluded that the change of both NSF-WQI and CCME-WQI due to climate change is controlled by changing of inflow more than the change of air temperature as inflow change affects most of the water quality used parameters, which in turn affect water quality state of the reservoir. A long time trend water quality state study for AHD reservoir should be done using a detailed database. Such study controls water quality management of the reservoir.

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