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Modeling versus Remote Sensing Techniques for Water Quality Monitoring in Deltaic Coastal Lake in Egypt

Hala O. Abayazid and Ahmed El-Adawy

Abstract: ***Coastal zone of Nile Delta experience challenges with excessive developments and concerns with climate change impact. Ensuring sustainability and strengthened adaptive capacity require an integrative base of information as well as regular monitoring for management planning. Difficulties with spatial coverage and frequency of field-based data collection triggered the need to seek other methods to fill the gaps. While employing numerical modeling proved acceptable performance in certain water quality predictions, the advancing Remote Sensing (RS) techniques provide a vast pool of spatial, temporal and multispectral data that are useful in information retrieval. This research investigates reliability degree of remotely sensed (Landsat-8) water quality parameters versus Model (Delft3D) predictions. Through an application in a deltaic coastal lake, the study presents a comparative analysis that address aspects such as pre-processing requirements, provided inputs, constraints in coverage, processing complexity as well as accuracy of concluded results for modeling versus space-based remote sensing techniques. Despite the dynamic nature and zonation featuring the water body under consideration, accuracy of model-predicted and satellite-retrieved water quality parameters [Total Suspended Sediments (TSS), Chlorophyll-a, Ortho-Phosphate (PO4), Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), Temperature], proved acceptably correlated (R^2 ranges0.73 - 0.86 and 0.69-0.87); respectively. However, the comparative analysis highlighted positive and negative issues of each technique and, accordingly, established guidance factors to consider by decision makers in prioritization and selection criteria based on management requirements. With proved effectiveness, regular assessment and wide spatio-temporal water quality database is feasible with complementary functioning of modeling and remote sensing techniques.***

Key words: Lake Edku, Nile Delta, Landsat Imagery, Coastal Zone

I. INTRODUCTION

The Nile Delta Coastal plain has been experiencing formation changes, mostly by continuous discharge of Nile branches into the Mediterranean Sea, during different successive phases [1]. Since the beginning of the 20th century, deltaic deposition has decreased and serious erosion has been occurring in several locations the northern coastal zone of the Delta is considered an active region with expanding developments that compromise self-recovery mechanism. Concerns with sustainability become more problematic with potential risk of climate change impact. With progressive anthropogenic intrusion, along with increasing demand on water resources, beneficial capacity needs to be maintained through quality management strategy. Yet managed sustainability with development processes, as well as strengthened adaptivity to potential climate change impact, requires an integrative base of information and regular monitoring. Conventional field-based measurements and sampling methods for water quality evaluation are customarily faced by limitations in frequency and spatial coverage, with possible economic and accessibility constrains. However, advances in Earth Observation (EO) technique and numerical modeling offer alternative spatio-temporal data source. Literature presents successful applications with several hydrodynamic-water quality models applied world-wide; such as, WASP, MIKE21, CE-QUAL-W2 and Delft3D [2] and [3]. Also, early studies showed applications of effective use of remote sensing products and satellite images to derive water quality properties (e.g. [4], [5], and [6]). Nonetheless, the selection of the technique to employ requires cautionary considerations.

Through an application in the deltaic coastal lake of Edku, the current study intends to present comparative performance for two of the ever-advancing techniques employed in water quality monitoring; coupled hydrodynamic-water quality modeling (Delft3D) simulation results versus space-based (Landsat8- Operational Land Imager (OLI)) retrieved properties. Model-predicted and satellite-retrieved water quality parameters considered in this study cover representative categories; namely, Total Suspended Sediments (TSS), Chlorophyll-*a* (Chl-a), Ortho-Phosphate (PO4), Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), Temperature, E.coli and Turbidity. Critical assessment addresses aspects such as; applicability, practicality, pre-requisite and processing constraints, effectiveness and accuracy as validated with field observations, hence confidence degree on results achieved.

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Accordingly, and as strengths and limitations of each technique are highlighted, a set of decisive factors for favorable selection is established with relation to management requirements and regional conditions as well.

II. MATERIALs & METHODS

A. Study Area: Deltaic Coastal Lake of Edku

Lake Edku is located within an active coastal sector, Northwestern of the Nile Delta, between longitude 30°8'-30°23' E and latitude 31°10'-31°18' N (Figure 1). The lake is freely connected to the Mediterranean Sea with one opening "Al-Maadia" that allows localized tidal inflows. It is considered a shallow eutrophic lake that rarely exceeding 1.5 m depth, with dominant patches of aquatic plants; emergent reeds, submersed flora and floating water hyacinth. Edku Lake serves an active agri-urban basin and bordered by dense aquaculture practices. Consequently, the lake receives waters with different pollution characteristics from fish farming therapeutic drugs, nutrient-rich discharges from agricultural drainage network, as well as effluents from municipal WasteWater Treatment Plants (WWTPs) and industrial facilities [7], [8] and [9].

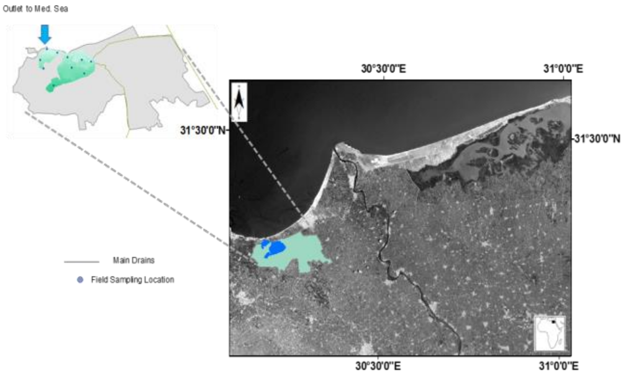

Figure 1: Lake Edku, showing data-collection locations.

B. Field Sampling Campaigns

Measurements for ground truth were acquired from the published technical research by [10]. The data were collected from ten sampling locations distributed throughout Lake Edku during the four seasons of year 2016. Field sampling was spatially distributed to sufficiently represent the variability in water quality with regard to boundary interaction as well as flow dynamics within the lake (Figure 1). Also consulted are the seasonally published reports by the Egyptian Environmental Affairs Agency [11].

C. Satellite Imagery and Model

In this research study, freely available space-based images and open source computer-based model have been chosen in order to discard purchase-related financial factor from the comparison equation. The satellite imageries used in the coastal lake application are the Landsat-8 Operational Land Imager (OLI), available in the United States Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov/). Acquisition time is the nearest corresponding overpass dates that match the field sampling timing. Landsat 8 (OLI) scenes used in the derivative algorithms have been acquired on dates 11th of March, 30th of May, 18th of August and 8th of December in year 2016. Imagery processing and result analysis were performed in Geographic Information System (GIS) environment.

	Coefficient of Determination (R^2)	
	Model	RS
Temperature	0.85	0.87
DO	0.73	0.79
Chl-a	N/A	0.69
TSS	N/A	0.81
BOD	0.77	N/A
PO4	0.86	N/A

Investigated water quality properties cover Temperature, Dissolved Oxygen DO, Turbidity, Total Suspended Sediments TSS and Chlorophyll-*a* levels within Lake Edku. Algorithms for retrieving water quality properties were developed using ratios of the extracted reflectance in the visible and Near-Infrared Spectral sector; visible bands (0.450 - 0.51μm, 0.53 - 0.59μm, 0.64 - 0.67μm), and Near-Infrared band (0.85 - 0.88μm). Meanwhile, surface water temperature levels were retrieved using Thermal Infrared bands (10.6 - 11.19μm and 11.5 - 12.51μm).

Meanwhile, numerical modeling was carried out using the Deltares coupled Delft3D-FLOW/WAQ model, equipped with programming modules that consecutively address the interactions between hydrodynamic and water quality processes. The developed orthogonal curvilinear grid covers Lake Edku with about 70000 cells. Computational gridding was initially of 20 m resolution, and then coarser gridding up to 300 m was applied for water quality modeling.

The model inputs require wide range of datasets; including lake geometric features, hydrodynamic and initial water quality characteristics (e.g. bathymetry, Boundary Conditions drainage tributary discharges, water level and tidal variation), along with meteorological datasets (wind vectors, solar radiation, relative humidity and temperature). Figure 2 illustrates the lake bathymetry on the developed model grid. First, the model simulates the interrelated mechanisms of water balance, meteorological and hydrologic forces. Consecutively, Delft3D-WAQ module utilizes the results calculated in the Delft3D-FLOW module via a coupling practice, and solves the advection-diffusion-reaction equations to follow the physical, chemical and biological changes in water quality status.

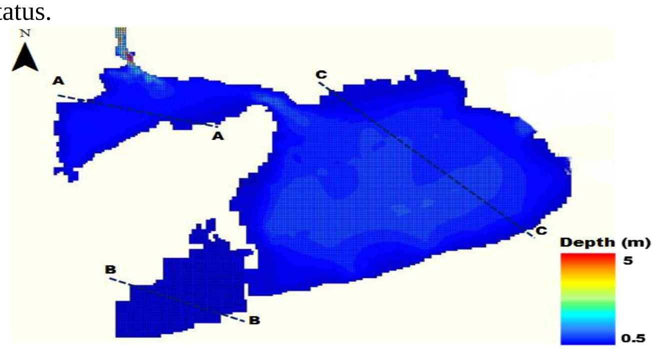

Figure 2: lake bathymetry on the developed model grid

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The input data used in this study were obtained from measurements collected by the Coastal Research Institute (CoRI), Okbah *et al.* [10] and seasonal reports of EEAA [11]. Also used are the databases offered by Delft Dashboard specially the bathymetry and tidal data for unmeasured areas (in sea side of the lake). Calibration process of the developed model was carried out for flow and water quality. Predicted parameters were compared against the independently measured data in selective observation stations. Fine tuning was mainly performed using water levels, reaeration transfer coefficient, as well as nitrification, mineralization, and decay rates.

III. RESULTS & DISCUSSION

This research study investigated water quality properties that cover three main categories of concern in the field of surface water quality management; Oxygen-related content, eutrophic state and pathogenic indicators. Both techniques derived water quality properties with acceptable accuracy. However, no technique covers all the water quality parameters sought. Each has capability of assessing certain set of water quality parameters. Remote sensing technique retrieved Temperature, Dissolved Oxygen (DO) Turbidity, Total Suspended Sediments (TSS) and Chlorophyll-a (Chl-a) levels within Lake Edku, with acceptable correlation range (R^2 =0.69- 0.87). Meanwhile, the model predicted Temperature, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), E-coli and Ortho-phosphate (PO4) concentrations within the lake, with acceptable correlation range (R^2 =0.73- 0.86). Table 1 states evaluated performance of both techniques, for selective water quality parameters, while figures (3A-D) and (4A-D) show sample results for modeled and remotely retrieved water quality parameters, respectively. Comparative results between model simulated versus Remote Sensing retrieved water quality state, in representative cross sections within the Edku Lake, are graphically illustrated in figures 5, 6 and 7.

Table 1: Performance evaluation for derived Water quality parameters using modeling versus remote sensing technique

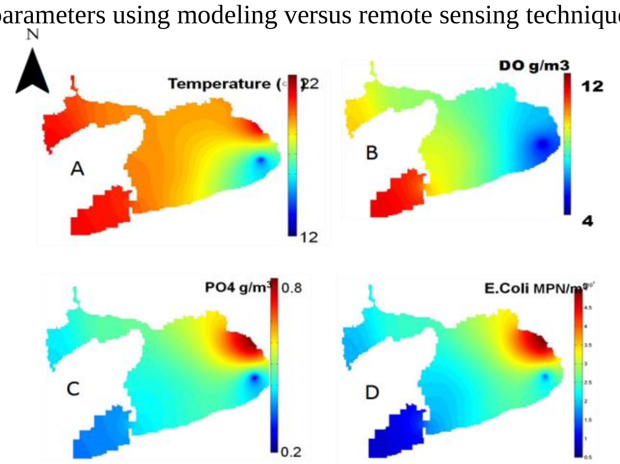

Figure 3 (A-D): Sample results for selective modeled water quality parameters- Spring, 2016.

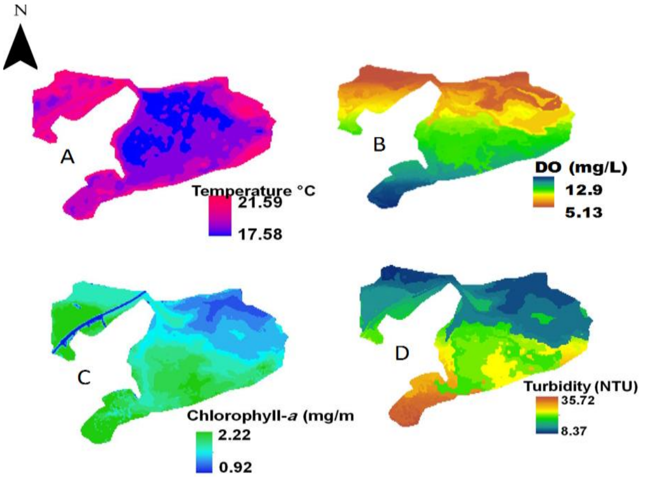

Figure 4 (A-D): Sample results for selective remotely retrieved water quality parameters- Spring, 2016.

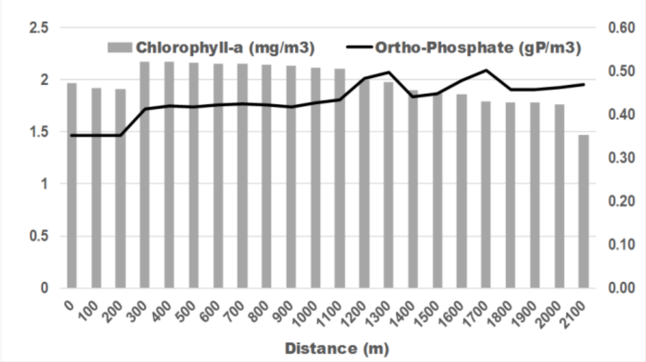

Figure5: Trophic state simulated by model versus retrieved by RS technique, in section A-A

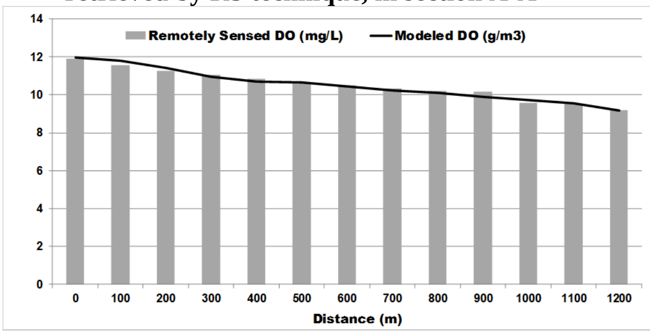

Figure 6: DO simulated by model versus retrieved by RS technique, in section B-B

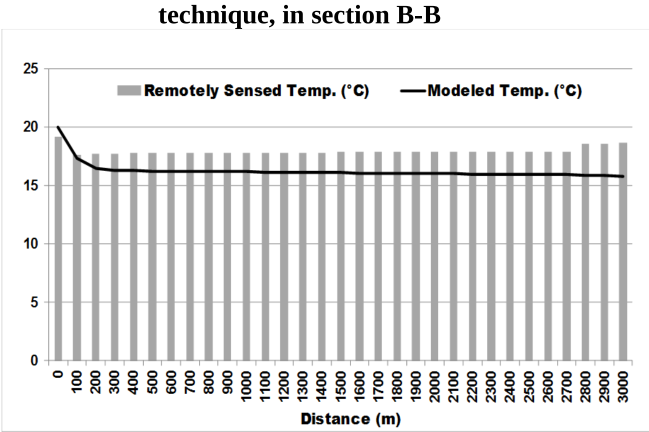

Figure7: Thermal state simulated by model versus retrieved by RS technique, in section C-C

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Based on the application on a deltaic coastal lake in Egypt, the following table (table 2) summarizes aspects in support or, otherwise, limitations of employing modelling and remote sensing techniques in the field of water quality monitoring.

Table 2: Positive and negative factors guiding the selection process between modelling and remote sensing techniques for water quality monitoring

	Model (Delft3D)	Space-based RS (Landsat8)
Pre-Processing	Detailed schematization and input datasets are required for thorough representation of the system modeled, so that proper simulation of the system dynamic behavior is achieved. e.g. model construction; gridding, boundary conditions, initial hydrodynamic and water quality setting, inputs parameterization and coefficients for model calculations…etc	Imagery requires rectification and corrections before analysis and algorithm development. Yet advancing software offer simpler image processing and data analysis.
Processing	The computational time can be problematic Long running time cause possible interruption by technical /power supply difficulties Ability to focus in certain location or time step of concern, based on the system dynamics. Modeler is capable of manipulating in gridding and temporal interval as needed. e.g. Possible fine grid resolution near spots of interest	Speedy and simple in processing Advancing software and calculation/statistical tools facilitate this stage Fixed spatial temporal, spectral resolutions of the imagery used. Landsat imagery has 16 days' revisit interval and 30-meter spatial resolution. However, vast leaps are acknowledged in this field, with improved space-based imagery temporal, spectral, and spatial resolutions. Repetitive processes for each WQ parameter to build distinct retrieval algorithm, and going through processing and accuracy testing individually
Results Presentation	Availability of friendly user-interface with clear, easily extracted outputs	Availability of friendly user-interface with clear, easily extracted outputs
Historical Tracking versus Future Prediction	Validated model can be used for predictions of system response under future conditions No capacity to build historical alteration, except with data that are already available	With archive imageries, a database with historical change in the area of interest can be established. Provide the possibility of tracking the evolution of different characteristics, and temporal developments of a phenomena or event. No capacity for future projection,

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		unless coupled with models for simulated predictions
Further Analysis; Sensitivity and Scenarios	Sensitivity analysis can highlight cause-effect relationship in the system modeled and, hence pinpoint source of problem. Hence, it would specify most influential factors in the changes predicted and/or quantify importance degree. Allow flexibility in modeling scenarios. Validated model can be used for predictions of system response under different conditions or proposed management measures	Mere interpretation of what is observed, but cannot provide justification or identify source of problem. No possibility to examine response of the system to proposed management measures
Constraints in Coverage	Once a comprehensive system component is constructed, the model provides more frequent observations for time steps that maybe not available with RS imageries passing time	Limited to optical water quality properties Data acquisition is restricted to satellite revisit interval that may vary from sampling field trips timing
Performance Evaluation and Reliability Degree	Acceptable simulation results	Acceptable retrieval results

IV. CONCLUSIONS

Deltaic coastal lakes of Egypt have strategic socio-economic and environmental importance. Yet progressive developments resulted in deterioration in water quality and, hence, ecosystem state, which necessitates regular monitoring for sustainability management. With increasing demand on reliable dataset as inputs for management planning and decision-making process, laborious, time- consuming field measurements become insufficient. Employing modeling and remote sensing techniques proved promising to overcome difficulties with temporal and spatial coverage. The study results demonstrated reasonable accuracy in retrieved water quality properties by both techniques, despite the dynamic nature and zonation featuring Edku Lake.Research findings for the comparative analysis between modeling and space-based remote sensing techniques underlined guiding factors to consider in prioritization and selection criteria, based on regional conditions, database availability, as well as management requirements. Findings revealed strengths and limitations of each technique; such as, input datasets requirements versus processing simplicity, historical tracking versus future prediction, sensitivity analysis, projection scenarios, constraints in coverage...etc.However, modeling and remote sensing techniques proved functioning successfully with complementary theme. Integrated use of remote sensing and modeling is leading to even better insight of system functions for decision makers and professionals in water resources management field.

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